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The prevalences and levels of occupational exposure to dusts and/or fibres (silica, asbestos and coal): A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury

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ABSTRACT

Background: The World Health Organization (WHO) and the International Labour Organization (ILO) are developing joint estimates of the work-related burden of disease and injury (WHO/ILO Joint Estimates), with contributions from a large number of individual experts. Evidence from human, animal and mechanistic data suggests that occupational exposure to dusts and/or fibres (silica, asbestos and coal dust) causes pneumoconiosis. In this paper, we present a systematic review and *meta*-analysis of the prevalences and levels of occupational exposure to silica, asbestos and coal dust. These estimates of prevalences and levels will serve as input data for

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Exposure levels
Systematic review

estimating (if feasible) the number of deaths and disability-adjusted life years that are attributable to occupational exposure to silica, asbestos and coal dust, for the development of the WHO/ILO Joint Estimates.
Objectives: We aimed to systematically review and *meta*-analyse estimates of the prevalences and levels of occupational exposure to silica, asbestos and coal dust among working-age (≥ 15 years) workers.
Data sources: We searched electronic academic databases for potentially relevant records from published and unpublished studies, including Ovid Medline, PubMed, EMBASE, and CISDOC. We also searched electronic grey literature databases, Internet search engines and organizational websites; hand-searched reference lists of previous systematic reviews and included study records; and consulted additional experts.
Study eligibility and criteria: We included working-age (≥ 15 years) workers in the formal and informal economy in any WHO and/or ILO Member State but excluded children (< 15 years) and unpaid domestic workers. We included all study types with objective dust or fibre measurements, published between 1960 and 2018, that directly or indirectly reported an estimate of the prevalence and/or level of occupational exposure to silica, asbestos and/or coal dust.
Study appraisal and synthesis methods: At least two review authors independently screened titles and abstracts against the eligibility criteria at a first stage and full texts of potentially eligible records at a second stage, then data were extracted from qualifying studies. We combined prevalence estimates by industrial sector (ISIC-4 2-digit level with additional merging within Mining, Manufacturing and Construction) using random-effects *meta*-analysis. Two or more review authors assessed the risk of bias and all available authors assessed the quality of evidence, using the ROB-SPEO tool and QoE-SPEO approach developed specifically for the WHO/ILO Joint Estimates.
Results: Eighty-eight studies (82 cross-sectional studies and 6 longitudinal studies) met the inclusion criteria, comprising > 2.4 million measurements covering 23 countries from all WHO regions (Africa, Americas, Eastern Mediterranean, South-East Asia, Europe, and Western Pacific). The target population in all 88 included studies was from major ISCO groups 3 (Technicians and Associate Professionals), 6 (Skilled Agricultural, Forestry and Fishery Workers), 7 (Craft and Related Trades Workers), 8 (Plant and Machine Operators and Assemblers), and 9 (Elementary Occupations), hereafter called manual workers. Most studies were performed in Construction, Manufacturing and Mining. For occupational exposure to silica, 65 studies (61 cross-sectional studies and 4 longitudinal studies) were included with > 2.3 million measurements collected in 22 countries in all six WHO regions. For occupational exposure to asbestos, 18 studies (17 cross-sectional studies and 1 longitudinal) were included with > 20,000 measurements collected in eight countries in five WHO regions (no data for Africa). For occupational exposure to coal dust, eight studies (all cross-sectional) were included comprising > 100,000 samples in six countries in five WHO regions (no data for Eastern Mediterranean). Occupational exposure to silica, asbestos and coal dust was assessed with personal or stationary active filter sampling; for silica and asbestos, gravimetric assessment was followed by technical analysis.
Risk of bias profiles varied between the bodies of evidence looking at asbestos, silica and coal dust, as well as between industrial sectors. However, risk of bias was generally highest for the domain of selection of participants into the studies.
The largest bodies of evidence for silica related to the industrial sectors of Construction (ISIC 41–43), Manufacturing (ISIC 20, 23–25, 27, 31–32) and Mining (ISIC 05, 07, 08). For Construction, the pooled prevalence estimate was 0.89 (95% CI 0.84 to 0.93, 17 studies, I^2 91%, moderate quality of evidence) and the level estimate was rated as of very low quality of evidence. For Manufacturing, the pooled prevalence estimate was 0.85 (95% CI 0.78 to 0.91, 24 studies, I^2 100%, moderate quality of evidence) and the pooled level estimate was rated as of very low quality of evidence. The pooled prevalence estimate for Mining was 0.75 (95% CI 0.68 to 0.82, 20 studies, I^2 100%, moderate quality of evidence) and the pooled level estimate was 0.04 mg/m^3 (95% CI 0.03 to 0.05, 17 studies, I^2 100%, low quality of evidence). Smaller bodies of evidence were identified for Crop and animal production (ISIC 01; very low quality of evidence for both prevalence and level); Professional, scientific and technical activities (ISIC 71, 74; very low quality of evidence for both prevalence and level); and Electricity, gas, steam and air conditioning supply (ISIC 35; very low quality of evidence for both prevalence and level).
For asbestos, the pooled prevalence estimate for Construction (ISIC 41, 43, 45,) was 0.77 (95% CI 0.65 to 0.87, six studies, I^2 99%, low quality of evidence) and the level estimate was rated as of very low quality of evidence. For Manufacturing (ISIC 13, 23–24, 29–30), the pooled prevalence and level estimates were rated as being of very low quality of evidence. Smaller bodies of evidence were identified for Other mining and quarrying (ISIC 08; very low quality of evidence for both prevalence and level); Electricity, gas, steam and air conditioning supply (ISIC 35; very low quality of evidence for both prevalence and level); and Water supply, sewerage, waste management and remediation (ISIC 37; very low quality of evidence for levels).
For coal dust, the pooled prevalence estimate for Mining of coal and lignite (ISIC 05), was 1.00 (95% CI 1.00 to 1.00, six studies, I^2 16%, moderate quality of evidence) and the pooled level estimate was 0.77 mg/m^3 (95% CI 0.68 to 0.86, three studies, I^2 100%, low quality of evidence). A small body of evidence was identified for Electricity, gas, steam and air conditioning supply (ISIC 35); with very low quality of evidence for prevalence, and the pooled level estimate being 0.60 mg/m^3 (95% CI −6.95 to 8.14, one study, low quality of evidence).
Conclusions: Overall, we judged the bodies of evidence for occupational exposure to silica to vary by industrial sector between very low and moderate quality of evidence for prevalence, and very low and low for level. For occupational exposure to asbestos, the bodies of evidence varied by industrial sector between very low and low quality of evidence for prevalence and were of very low quality of evidence for level. For occupational exposure to coal dust, the bodies of evidence were of very low or moderate quality of evidence for prevalence, and low for level. None of the included studies were population-based studies (i.e., covered the entire workers' population in the industrial sector), which we judged to present serious concern for indirectness, except for occupational exposure to coal dust within the industrial sector of mining of coal and lignite. Selected estimates of the prevalences and levels of occupational exposure to silica by industrial sector are considered suitable as input data for the WHO/ILO Joint Estimates, and selected estimates of the prevalences and levels of occupational exposure to asbestos and coal dust may perhaps also be suitable for estimation purposes.
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CRD42018084131.

1. Background

The World Health Organization (WHO) and the International Labour Organization (ILO) produce the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury (WHO/ILO Joint Estimates) (Pega et al. 2021a; World Health Organization and International Labour Organization 2021a; World Health Organization; International Labour Organization 2021b; Pega et al. 2022a). The organizations estimate the numbers of deaths and disability-adjusted life years (DALYs) that are attributable to selected occupational risk factors. The WHO/ILO Joint Estimates are based on already existing WHO and ILO methodologies for estimating the burden of disease for selected occupational risk factors (International Labour Organization 2014; Prüss-Ustün et al. 2017). They expand these existing methodologies with estimation of the burden of several prioritized additional pairs of occupational risk factors and health outcomes. For this purpose, population attributable fractions, the proportional reduction in burden from the health outcome achieved by a reduction of exposure to the theoretical minimum risk exposure level (Murray et al. 2004), are calculated for each additional risk factor-outcome pair. These fractions are applied to the total burden of disease envelopes for the health outcome from the WHO Global Health Estimates (World Health Organization 2018).

The WHO/ILO Joint Estimates may include a methodology for estimating, and estimates of the burden of silicosis, asbestosis and coal workers' pneumoconiosis attributable to occupational exposure to silica dust, asbestos fibres and coal (mine) dust, respectively, if feasible, as additional prioritized risk factor-outcome pairs. To select parameters with the best and least biased evidence for our estimation models, we conducted a systematic review and *meta*-analysis of studies on the prevalence and level of occupational exposure to these dusts and/or fibres, as per our protocol (Mandrioli et al. 2018). WHO and ILO, supported by a large number of individual experts, are in parallel also producing a systematic review and *meta*-analysis of the health effects of occupational exposure to silica, asbestos and coal (mine) dust on silicosis, asbestosis and coal workers' pneumoconiosis (Mandrioli et al. 2018). The organizations are also conducting or have completed several other systematic reviews and *meta*-analyses on other additional risk factor-outcome pairs (Descatha et al., 2018, 2020; Godderis et al., 2018; Li et al., 2018, 2020; Loomis et al., 2022; Pachito et al., 2021; Paulo et al., 2019; Pega et al., 2020b; Rugulies et al., 2019, 2021; Teixeira et al., 2021a; Tenkate et al., 2019; World Health Organization, 2021; Hulshof et al., 2019; Hulshof et al., 2021a; Hulshof et al., 2021b; Teixeira et al., 2019; Teixeira et al., 2021b). To our knowledge, these are the first systematic reviews and *meta*-analyses (with a pre-published protocol, Mandrioli et al. (2018)) conducted specifically for an occupational burden of disease study. An editorial provides an overview of this series of systematic reviews and *meta*-analyses from the WHO/ILO Joint Estimates and outlines its scientific, methodological, policy, editorial and other innovations (Pega et al. 2021b). Several new systematic review methods were also developed specifically for the WHO/ILO Joint Estimates (Pega et al. 2020a; Momen et al. 2022; Pega et al. 2022c; Pega et al. 2022b). The WHO/ILO joint estimation methodology and the WHO/ILO Joint Estimates are separate from these systematic reviews, and they are described in more detail and reported elsewhere (Pega et al. 2021a; World Health Organization and International Labour Organization 2021a,b; Nafradi et al. 2022; Pega et al. 2022a). For example, WHO/ILO Joint Estimates have been published of the global, regional and national burdens of ischemic heart disease and stroke attributable to exposure to long working hours for 183 countries (Pega et al. 2021a).

1.1. Rationale

Occupational exposures to asbestos, silica and coal dust (defined as pure coal dust and dust from coal mining) are known occupational risk factors for pneumoconiosis. In the Global Burden of Disease Study 2016, asbestosis (as an outcome separate to coal workers' pneumoconiosis and other pneumoconiosis) and silicosis are 100% attributed to occupational exposure to asbestos and silica respectively (G. B. D. Risk Factors Collaborators 2017). In the same study, the entire burden of coal workers' pneumoconiosis and of other pneumoconiosis is 100% attributed to the risk factors occupational exposure to particulate matter, gases and fumes (G. B. D. Risk Factors Collaborators 2017). However, the population-attributable fractions may actually be smaller than 1.00, considering that some burden of pneumoconiosis may be caused by residential exposure to one or more sources of asbestos (Tarres et al. 2013), silica and coal dust (Akaoka et al. 2017) among residents near mines; non-occupational exposure to silica from the natural environment (e.g. wind erosion and storms, including in deserts) (De Berardis et al. 2007); and from second-hand exposures (e.g. family members of exposed workers coming into contact with contaminated clothes etc.). To consider the feasibility of estimating the burden of pneumoconiosis from occupational exposure by inhalation of dusts and/or fibres, and to ensure that potential estimates of burden of disease are reported in adherence with the guidelines for accurate and transparent health estimates reporting (GATHER) (Stevens et al. 2016), WHO and ILO require a systematic review of studies on the prevalence of any occupational exposure to dusts and/or fibres, as well as a systematic review and *meta*-analysis of studies with estimates of the relative effect of occupational exposure to dusts and/or fibres on the prevalence of, incidence of and mortality from pneumoconiosis, compared with the theoretical minimum risk exposure level. The theoretical minimum risk exposure level is the exposure level that would result in the lowest possible population risk, even if it is not feasible to attain this exposure level in practice (Murray et al. 2004). These data and effect estimates should be tailored to serve as parameters for estimating the burden of pneumoconiosis from occupational exposure to silica, asbestos and coal dust in the WHO/ILO joint methodology. Apart from one systematic review assessing exposure to pure coal dust and the risk of interstitial lung diseases (Beer et al. 2017), we have not identified any previous systematic reviews on occupational exposure to dusts and/or fibres. However, there was a recent scoping review which looked at occupational exposure of silica and asbestos among industrial workers in Thailand (Kunpeuk et al. 2021). This study reported prevalence of exposure to be 100% in most of the included studies.

Our systematic review covers studies on workers in the formal and informal economy. The informal economy is defined as "all economic activities by workers and economic units that are – in law or in practice – not covered or insufficiently covered by formal arrangements" (104th International Labour Conference 2015). It does not comprise "illicit activities, in particular the provision of services or the production, sale, possession or use of goods forbidden by law, including the illicit production and trafficking of drugs, the illicit manufacturing of and trafficking in firearms, trafficking in persons and money laundering, as defined in the relevant international treaties" (104th International Labour Conference 2015). Work in the informal economy may lead to different exposures and exposure effects than does work in the formal economy. Therefore, we consider in the systematic review the formality of the economy reported in included studies.

Table 1
Definitions of the risk factors, risk factor levels and the minimum risk exposure levels.

Risk factor	Occupational exposure to silica	Occupational exposure to asbestos	Occupational exposure to coal dust
Risk factor levels	Two levels: No occupational exposure to silica Any occupational exposure to silica	Two levels: No occupational exposure to asbestos Any occupational exposure to asbestos	Two levels: No occupational exposure to coal dust Any occupational exposure to coal dust
Theoretical minimum risk exposure level	No occupational exposure to silica	No occupational exposure to asbestos	No occupational exposure to coal dust

Footnote: Sourced from Mandrioli et al. (2018).

1.2. Description of the risk factor

We have reviewed occupational exposure to three different types of dusts and/or fibres: (i) silica; (ii) asbestos; and (iii) coal dust. We define coal dust as dust from coal mining or dust from pure coal. Coal dust from coal mining may contain a combination of different types of coal, silica, various silicates and asbestos fibres, depending on the specific mineral composition of the mined substance. There are workers with exposure to coal dust only, such as those working in (bulk) transportation (e.g. bulk ports) and who use coal at work (e.g. coke ovens, electricity power plants and other industries using coal as ground material or power source). However, the most numerous occupational groups with exposure to coal dust include workers involved in excavating coal at the seam of coal mines and those working in downstream activities (e.g., haulage, maintenance and surface workers). The definition of the risk factors, the risk factor levels and their theoretical minimum risk exposure level are presented in Table 1. We define the risk factors as any occupational exposure by inhalation to silica dust, asbestos fibres or coal dust in the air. A priori, we assumed a theoretical minimum risk exposure level of no occupational exposure. Where possible we used the analytical limit of detection (LOD) as the cut-off between exposed and unexposed. For studies with a different cut-off between exposed and non-exposed, we converted reported levels to the standard levels and, if not possible, we included studies with these alternate exposure levels in the systematic review and discussed the implications.

2. Objectives

To systematically review and *meta*-analyse evidence on the prevalences and levels of occupational exposure to silica, asbestos and coal dust among working-age (≥ 15 years) workers.

3. Methods

3.1. Developed protocol

The study protocol was registered in PROSPERO (CRD42018084131). This protocol is in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols statement (PRISMA-P) (Moher et al. 2015; Shamseer et al. 2015). The abstract is in line with the Reporting Items for Systematic Reviews in journal and conference Abstracts (PRISMA-A) (Beller et al. 2013). Any modification of the methods stated in the protocol is reported in *Section 8*. Our systematic review is reported according to the Preferred Reporting Items for Systematic Review and Meta-Analysis statement (PRISMA) (Liberati et al. 2009). Our reporting of the parameters for estimating occupational exposure to silica, asbestos and coal dust in the systematic review adheres with the requirements of the Guidelines for Accurate and Transparent Health Estimates Reporting guidelines (Stevens et al. 2016). This is done because the WHO/ILO Joint Estimates that may be produced following the systematic review must also adhere to these reporting guidelines.

3.2. Searched literature

3.2.1. Electronic academic databases

We searched the following electronic academic databases:

1. Ovid Medline with Daily Update (1946 to 22 May 2018).
2. PubMed (1946 to 20 June 2018).
3. EMBASE (1974 to 5 June 2018).
4. Web of Science with inclusion of three databases:
   (a) Science Citation Index Expanded (1900 to 17 June 2018).
   (b) Social Sciences Citation Index (1956 to 30 April 2018).
   (c) Arts and Humanities Citation Index (1975 to 30 April 2018).
5. OSH UPDATE with inclusion of three databases:
   (a) CISDOC (1974 to 14 June 2018).
   (b) HSELINE (1977 to 30 April 2018).
   (c) NIOSHTIC-2 (1977 to 14 June 2018).

All search strategies are presented in Appendix 1 in the Supplementary data. We searched in electronic databases operated in the English language using a search strategy in the English language. We adapted the Ovid Medline search syntax to suit the other electronic academic and grey literature databases.

3.2.2. Electronic grey literature databases

We searched the following electronic academic databases:

1. OpenGrey (https://www.opengrey.eu/).
2. Grey Literature Report (https://greylit.org/).

3.2.3. Internet search engines

We also searched the Google (https://www.google.com/) and Google Scholar (https://www.google.com/scholar/) Internet search engines and screened the first 100 hits for potentially relevant records, as has been done in Cochrane Reviews previously (Pega et al. 2022d).

3.2.4. Organizational websites

The websites of the following seven international organizations and national government departments were searched:

i. International Labour Organization (https://www.ilo.org).
ii. World Health Organization (https://www.who.int).
iii. European Agency for Safety and Health at Work (https://osha.europa.eu/en).
iv. Eurostat (https://www.ec.europa.eu/eurostat/web/main/home).
v. China National Knowledge Infrastructure (https://www.cnki.net/).
vi. Finnish Institute of Occupational Health (https://www.ttl.fi/en/).
vii. United States National Institute of Occupational Safety and Health (NIOSH), using the NIOSH data and statistics gateway (https://www.cdc.gov/niosh/data/).

3.2.5. Hand-searching and expert consultation

We hand searched for potentially eligible studies in:

- Reference lists of previous systematic reviews.
- Reference lists of all included study records.
- Study records published over the previous 24 months in the three peer-reviewed academic journals from which we obtained the largest number of included studies.
- Study records that have cited an included study record (identified in the Web of Science citation database).
- Collections of the review authors.

Additional experts were contacted with a list of included studies, with the request to identify potentially eligible additional studies.

3.2.6. National information searches

Review authors from four national government agencies conducted searches of national and local bibliographic and grey literature databases for their countries (Bulgaria, People's Republic of China, South Africa, and Thailand) in their national language or languages:

- National Center of Public Health and Analyses, Ministry of Health, Bulgaria.
- National Institute for Occupational Health and Poison Control, Chinese Center for Disease Control and Prevention, People's Republic of China.
- National Institute for Occupational Health, South Africa.
- International Health Policy Program, Ministry of Public Health, Thailand.

3.3. Selected studies

Study selection was carried out with the Systematic Review tool Covidence (https://www.covidence.org). All study records identified in the search were downloaded to Endnote, and then duplicates were identified and deleted. Afterwards, at least two review authors independently screened titles and abstracts (step 1) and then full texts (step 2) of potentially relevant records. A third review author resolved disagreements between the two review authors. If a study record identified in the literature search was authored by a review author assigned to study selection or if an assigned review author was involved in the study, then the record was re-assigned to another review author for study selection. In the systematic review, the study selection process was documented in a flow chart, as per GATHER guidelines (Stevens et al. 2016).

3.4. Eligibility criteria

The population and exposure criteria are described below.

3.4.1. Types of populations

We included studies of working-age ($\geq$ 15 years) workers in the formal or informal economy. Studies of children (aged < 15 years) and unpaid domestic workers were excluded. Participants residing in any WHO Member and/or ILO member State and workers in any industrial sector and occupation were included.

3.4.2. Types of exposures

We included studies that define occupational exposure to dusts and/or fibres in accordance with our standard definition (Table 1). For pneumoconiosis, cumulative exposure is the most biologically relevant exposure metric, but we also considered a non-cumulative exposure metric when insufficient cumulative exposure data were available to enable burden of disease estimation. We reviewed evidence separately for dusts and/or fibres from (i) asbestos, (ii) silica and (iii) coal dust. We included studies with direct or indirect information on the prevalences and levels of occupational exposure to the respective risk factor, possibly disaggregated by country, sex (two categories: female, male), age group (ideally in 5-year age bands, such as 20–24 years) and industrial sector (e.g. International Standard Industrial Classification of All Economic Activities, Revision 4 [ISIC Rev.4] (United Nations 2008) or occupation (as defined, for example, by the International Standard Classification of Occupations 1988 [ISCO-88] (International Labour Organization 1988) or 2008 [ISCO-08] (International Labour Organization 2012). To be included, studies should as a minimum present data disaggregated by Country and Industry/Occupation. We included studies with exposure data for the years 1960 to June 2018. We included only studies with objective measurements of occupational exposure to eligible dusts and/or fibres, such as quantitative samples of dusts and/or fibres collected by an expert using appropriate technologies. Subjective measures were excluded, such as self-reports from workers, workplace administrators or managers. We included studies with measures from any data source, including registry data.

The eligible exposure measures of this systematic review were:

1. Prevalence of any occupational exposure to silica
2. Level of occupational exposure to silica among exposed workers
3. Prevalence of any occupational exposure to asbestos
4. Level of occupational exposure to asbestos among exposed workers
5. Prevalence of any occupational exposure to coal dust
6. Level of occupational exposure to coal dust among exposed workers

3.4.3. Types of studies

We included quantitative studies of any design. These studies were judged to be informative of the relevant industrial sector, occupational group or national population. We excluded qualitative, modelling and case studies, as well as non-original studies without quantitative data (e.g. letters, commentaries and perspectives). Records written in any language were included. If a record was written in a language other than those spoken by the authors of this review or those of other reviews (Descatha et al. 2018; Godderis et al. 2018; Li et al. 2018; Mandrioli et al. 2018; Hulshof et al. 2019; Paulo et al. 2019; Rugulies et al. 2019; Teixeira et al. 2019; Tenkate et al. 2019; Descatha et al. 2020; Li et al. 2020; Pega et al. 2020b; Hulshof et al. 2021b; Hulshof et al. 2021a; Pachito et al. 2021; Rugulies et al. 2021; Teixeira et al. 2021b; Teixeira et al. 2021a; World Health Organization 2021; Loomis et al. 2022) in the series (i.e. Arabic, Bulgarian, Chinese, Danish, Dutch, English, French, Finnish, German, Hungarian, Italian, Japanese, Norwegian, Portuguese, Russian, Thai, Spanish, and Swedish), then the record was translated into English. Published and unpublished studies were included. Studies conducted using unethical practices were excluded from the review (e.g., studies that deliberately exposed humans to a known risk factor to human health); none were however found.

3.4.4. Types of prevalence and level measures

We included studies with a direct or indirect measure of exposure prevalence and/or exposure level.

Exposure can be defined as contact between an agent and a target. Contact takes place at an exposure surface over an exposure period (ES21 Federal Working Group on Exposure Science 2015) The prevalence (as here defined) is usually measured as the number of exposed persons (numerator) divided by the total number of persons (i.e., unexposed persons plus exposed persons) (denominator). It is usually reported in percentage points.

The exposure level is measured in the unit milligram per cubic meter (mg/m^3) for silica and coal dust and in fibre per millilitre (f/ml) for asbestos.

3.5. Extracted data

WHO and ILO developed a standard data extraction sheet and all data extractors piloted this sheet until there was convergence and

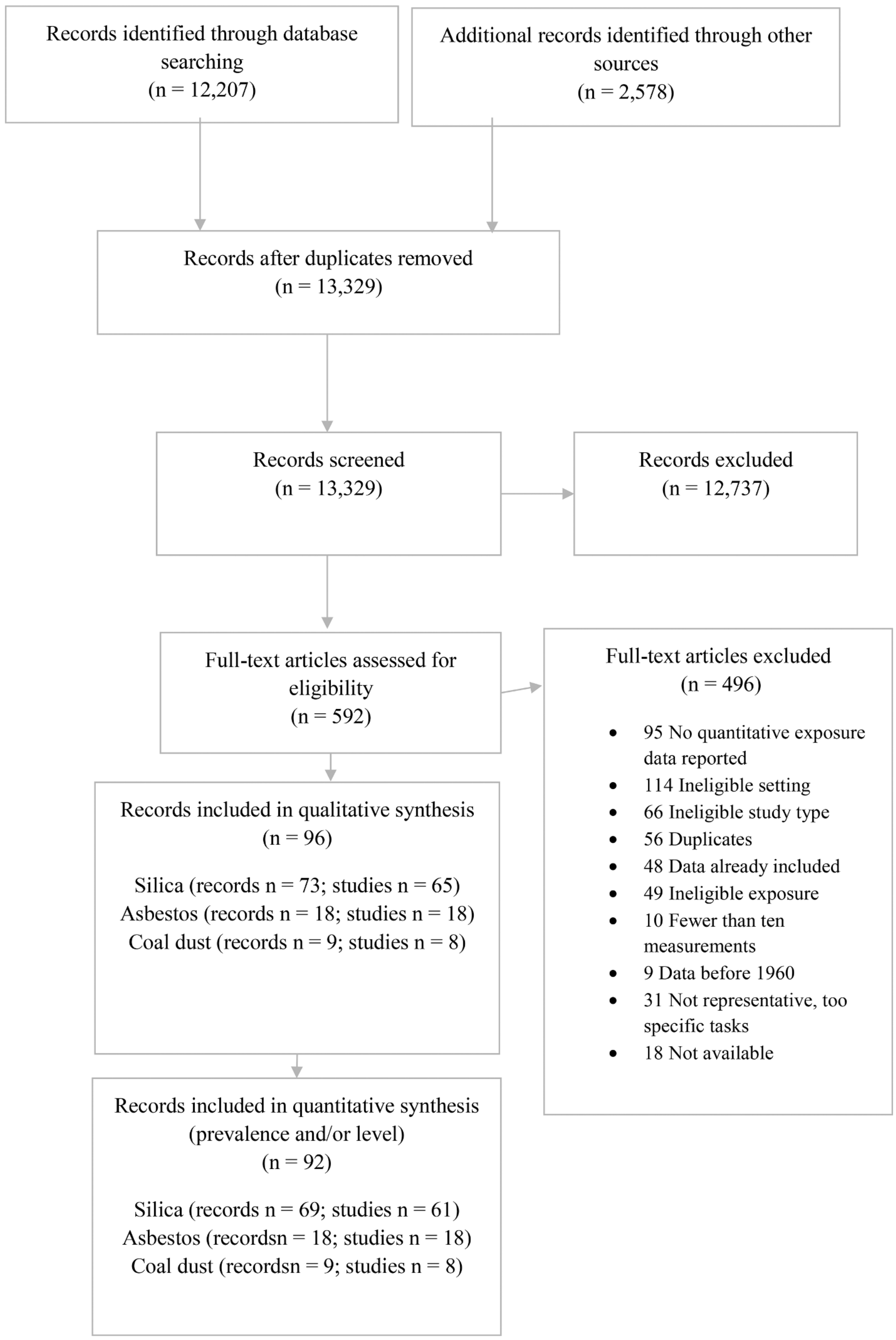

Fig. 1. Flow diagram of study selection.

Table 2
Characteristics of included studies, Prevalence and level of occupational exposure to silica.

Study	Inclusion in *meta*-analyses?	Study population								
Study ID	**Industrial sector and estimate type**	**Number of measurements**	**Number of participants**	**Number of female participants**	**Country**	**Geographic location**	**Target population**	**Industrial sector, ISIC-4**	**Occupation, ISCO-08**	**Age distribution**
Andersson 2009 (Andersson et al. 2009; Andersson et al. 2012)	Manufacturing (prevalence and level)	2333	1691	Unclear	Sweden	National	Manual iron foundries workers in Sweden	24 Manufacture of basic metals		Unclear
Archer 2002 (Archer et al. 2002)	Crop and animal production (prevalence and level)	37	27	Unclear	United States of America	Regional	Manual crop farm workers in North Carolina	01 Crop and animal production, hunting and related service activities	9211	Unclear
Azari 2009 (Azari et al., 2009)	Construction (prevalence and level); Manufacturing (prevalence and level); Mining (prevalence and level)		194	Unclear	Iran (Islamic Republic of)	Local	Exposed manual workers from various industries in Tehran, Iran (Islamic Republic of)	08 Other mining and quarrying		Unclear
		40						*08 Other mining and quarrying*		*Unclear*
		20						*24 Manufacture of basic metals*		*Unclear*
		20						*42 Civil engineering*		*Unclear*
		20						*41 Construction of buildings*		*Unclear*
		80						23 Manufacture of other non-metallic mineral products		*Unclear*
		14						*32 Other manufacturing*		*Unclear*
Bakke 2001(Bakke et al. 2001)	Construction (prevalence and level)	386	209	0	Norway	National	Manual tunnel construction workers in Norway	42 Civil engineering	8113	Unclear
Bakke 2014 (Bakke et al. 2014)	Construction (prevalence and level)	162	209	0	Norway	National	Manual tunnel construction workers in Norway	42 Civil engineering	8113	Unclear
Carneiro 2017 (Carneiro et al. 2017)	Manufacturing (prevalence and level)	50		0	Brazil	Region	Semi-precious stone craftsmen in Minas Gerais, Brazil	23 Manufacture of other non-metallic mineral products	7549	Nonsilicotics: Median 30, Range 17–62. Silicotics: Median 34, Range: 25–56
Chen 2012 (Chen et al. 2012)	Manufacturing (prevalence and level); Mining (prevalence and level)			10,514	China	National				
		1,388,085	*59,743*				*Manual metal mine workers in China*	*07 Mining of metal ores*	*8111*	*Unclear*
		782,644	*59,743*				*Manual metal mine workers in China*	*07 Mining of metal ores*	*8111*	*Unclear*
		357	*14,297*				*Manual pottery workers in China*	*23 Manufacture of other non-metallic mineral products*	*9329*	*Unclear*
		867	*14,297*				*Manual pottery workers in China*	*23 Manufacture of other non-metallic mineral products*	*9329*	*Unclear*

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Table 2 (*continued*)

Study	Inclusion in *meta*-analyses?	Study population								
Study ID	**Industrial sector and estimate type**	**Number of measurements**	**Number of participants**	**Number of female participants**	**Country**	**Geographic location**	**Target population**	**Industrial sector, ISIC-4**	**Occupation, ISCO-08**	**Age distribution**
Chen 2007 (Chen et al. 2007)	Manufacturing (prevalence)	64		Unclear	Taiwan, China	Region	Manual refractory workers in Taiwan, China	23 Manufacture of other non-metallic mineral products	9329	Unclear
Churchyard 2004 (Churchyard et al. 2004)	Mining (prevalence and level)	506	112	Unclear	South Africa	Local	Manual work goldminers in South Africa	07 Mining of metal ores	8111	Above 40
Dion 2005 (Dion et al. 2005)	Manufacturing (prevalence)	28	48	Unclear	Canada	Region	Manual workers in silicon carbide production plants in Canada	20 Manufacture of chemicals and chemical products	9329	Unclear
Estellita 2010 (Estellita 2010)	Manufacturing (prevalence); Mining (prevalence)				Brazil	Region				Unclear
		78		*0*			*Manual granite shop workers in Brazil*	*23 Manufacture of other non-metallic mineral products*	*9329*	
		14		*0*			*Manual granite miners in Brazil*	*08 Other mining and quarrying*	*8111*	
Flanagan 2006 (Flanagan et al. 2006)		1374		Unclear	United States of America	National	Manual construction workers in the United States of America	41 Construction of buildings	9313	Unclear
Foreland 2008 (Føreland et al. 2008)	Manufacturing (prevalence and level)	680	250	Unclear	Norway	National	Manual silicon carbide workers in Norway	23 Manufacture of other non-metallic mineral products	9329	Unclear
Fulekar 1999 (Fulekar 1999)				Unclear	India	Region	Quartz manufacturing industry workers in India	23 Manufacture of other non-metallic mineral products	9329	Unclear
Galea 2016 (Galea et al. 2016)	Construction (level)	49	25	Unclear	United Kingdom of Great Britain and Northern Ireland	Local	Manual tunnel workers in London, the United Kingdom of Great Britain and Northern Ireland	42 Civil engineering	2146	Unclear
Golbabaei 2004 (Golbabaei et al. 2004)	Mining (prevalence)	60	18	0	Iran (Islamic Republic of)	Local	Manual stone quarry workers in Iran (Islamic Republic of)	08 Other mining and quarrying	9311	Various age groups: mean 31
Gottesfeld 2015 (Gottesfeld et al. 2015)	Mining (prevalence and level)	11	27	Unclear	United Republic of Tanzania	Region	Manual artisanal small-Scale Gold Mining in the United Republic of Tanzania	07 Mining of metal ores	9311	Unclear
Green 2008 (Green et al. 2008)	Mining (prevalence)	79		19 samples	India	Region	Manual young workers in stone crushing sites in India	08 Other mining and quarrying	7113	Unclear
Grove 2014 (Grové et al. 2014)		42		Unclear	South Africa	National	Manual coal mine workers in South Africa	05 Mining of coal and lignite	9311	Unclear
Guenel 1989 (Guénel et al. 1989)	Construction (prevalence); Manufacturing (prevalence)				Denmark	National		42 Civil engineering		Unclear
		87		*Unclear*			*Manual road workers in Denmark*	42 Civil engineering	*9311*	
		21		*Unclear*			*Manual stone cutters in Denmark*	23 Manufacture of other non-metallic mineral products	*9311*	*Unclear*

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Table 2 (*continued*)

Study	Inclusion in *meta*-analyses?	Study population								
Study ID	Industrial sector and estimate type	Number of measurements	Number of participants	Number of female participants	Country	Geographic location	Target population	Industrial sector, ISIC-4	Occupation, ISCO-08	Age distribution
Hammond 2016 (Hammond et al. 2016)	Construction (prevalence and level)	42		Unclear	United States of America	Region	Manual asphalt pavement milling in the United States of America	42 Civil engineering	9313	Unclear
Hayumbu 2008 (Hayumbu et al. 2008)	Mining (prevalence)	203		Unclear	Zambia	Region	Manual copper mine workers in Zambia	07 Mining of metal ores	9311	Unclear
Healy 2014 (Healy et al. 2014)	Manufacturing (prevalence)	103		Unclear	Ireland	National	Manual stone-workers involved in stone restoration work in Ireland	23 Manufacture of other non-metallic mineral products	7113	Unclear
Hicks 2006 (Hicks and Yager 2006)	Electricity, gas, steam and air conditioning supply (prevalence)	108		Unclear	United States of America	Unclear	Manual coal power plant workers in the United States of America	35 Electricity, gas, steam and air conditioning supply	3131	Unclear
Huizer 2010 (Huizer et al. 2010)	Construction (prevalence)	22		unclear	Netherlands	National	Teachers and students in Bricklaying Vocational Training Centers in the Netherlands	43 Specialized construction activities	7112	Unclear
Khoza 2012 (Khoza 2012)	Construction (prevalence and level); Manufacturing (prevalence and level)			Unclear	South Africa	Region	Manual non-mining industry workers in South Africa			Unclear
		54					*Foundry workers in South Africa*	*24 Manufacture of basic metals*	*3135*	
		95		*Unclear*	*South Africa*	*Region*	*Sandstone/sandblasting workers in South Africa*	*23 Manufacture of other non-metallic mineral products*		
		49		*Unclear*	*South Africa*	*Region*	*Construction workers in South Africa*	*41 Construction of buildings*	*9313*	
		108		*Unclear*	*South Africa*	*Region*	*Ceramics/potteries/ refractories workers in South Africa*	*32 Other manufacturing*	*8181*	
		95		*Unclear*	*South Africa*	*Region*	*Sandstone/sandblasting workers South Africa*	*23 Manufacture of other non-metallic mineral products*		
		108		*Unclear*	*South Africa*	*Region*	*Ceramics/potteries/ refractories workers in South Africa*	*32 Other manufacturing*	*8181*	
Kim 2002 (Kim et al. 2002)	Professional, scientific and technical activities (level)	41	60	0	Republic of Korea	Region	Manual dental technician in the Republic of Korea	74 Other professional, scientific and technical activities	3251	Mean 36, SD 5.9
Koo 2000 (Koo et al., 2000)	Manufacturing (prevalence)	22	209	0	Republic of Korea	Region	Manual Foundry workers in the Republic of Korea	24 Manufacture of basic metals	3135	Unclear
Kreiss 1996 (Kreiss and Zhen 1996)	Mining (level)	484		Unclear	United States of America	Local	Manual mine workers in Colorado, the United States of America	07 Mining of metal ores	9311	Unclear

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Table 2 (*continued*)

Study	Inclusion in *meta*-analyses?	Study population								
Study ID	**Industrial sector and estimate type**	**Number of measurements**	**Number of participants**	**Number of female participants**	**Country**	**Geographic location**	**Target population**	**Industrial sector, ISIC-4**	**Occupation, ISCO-08**	**Age distribution**
Kullman 1995 (Kullman et al. 1995)	Mining (prevalence and level)	559	874	Unclear	United States of America	National	Manual workers in American stone mining and milling operations	08 Other mining and quarrying	8111	Unclear
Lee 2014 (Lee 2014)	Mining (prevalence)	14		Unclear	Republic of Korea	Region	Manual stone workers in construction industry in the Republic of Korea	08 Other mining and quarrying	7113	Unclear
Linch 2002 (Linch 2002)	Construction (prevalence)	45		Unclear	United States of America	Regions	Manual construction workers in the United States of America	41 Construction of buildings	9313	Unclear
Love 1997 (Love et al. 1997)	Mining (prevalence)	626	1249	25	United Kingdom of Great Britain and Northern Ireland	National	Manual workers in opencast coalmining in the United Kingdom of Great Britain and Northern Ireland	08 Other mining and quarrying	9311	Unclear
Love 1999 (Love et al. 1999)	Heavy clay industry (prevalence)	1403	1925	Unclear	United Kingdom of Great Britain and Northern Ireland	National	Workers in the heavy clay industry in the United Kingdom of Great Britain and Northern Ireland	23 Manufacture of other non-*metallic mineral products*	Various	Unclear
Mamuya 2006 (Mamuya et al. 2006b; Mamuya et al. 2006a)	Mining (prevalence and level)	173		0	United Republic of Tanzania	Region	Manual coal mine workers in the United Republic of Tanzania	08 Other mining and quarrying	9311	Unclear
Nieuwenhuijsen 1999 (Nieuwenhuijsen et al. 1999)	Crop and animal production (prevalence)	144		Unclear	United States of America	Region	Manual farmers in California, the United States of America	01 Crop and animal production, hunting and related service activities	6330	Unclear
Nij 2003 (Tjoe Nij et al. 2003; Tjoe Nij et al. 2004)	Construction (prevalence and level)	61		Unclear	Netherlands	National	Manual building construction workers in the Netherlands	41 Construction of buildings	9313	30–34 years
Normohammadi 2016 (Normohammadi et al. 2016)	Construction (prevalence and level)	60		Unclear	Iran (Islamic Republic of)	Region	Manual demolition workers in Iran (Islamic Republic of)	43 Specialized construction activities	9313	25–29 years
Omidianidost 2015 (Omidianidost et al. 2015; Omidianidost et al. 2016)	Manufacturing (prevalence)	80		Unclear	Iran (Islamic Republic of)	Local	Manual foundry workers in Iran (Islamic Republic of)	24 Manufacture of basic metals	7211	Unclear
Oudyk 1995 (Oudyk 1995)	Manufacturing (prevalence and level)	1038		Unclear	Canada	Unclear	Manual ferrous foundries workers in Ontario, Canada	24 Manufacture of basic metals	7221	Unclear
Pandey 2017 (Pandey 2017)	Mining (prevalence)	69		Unclear	India	Region.	Manual coal miners in Jharia, India	05 Mining of coal and lignite	8111	Unclear
Peters 2017 (Peters et al. 2017)	Mining (prevalence and level)			Unclear	Australia	Region	Mine workers in Australia including administrative workers	07 Mining of metal ores	9311	Unclear
		11,084								
		13,672								
		9180								

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Study	Inclusion in *meta*-analyses?	Study population								
Study ID	**Industrial sector and estimate type**	**Number of measurements**	**Number of participants**	**Number of female participants**	**Country**	**Geographic location**	**Target population**	**Industrial sector, ISIC-4**	**Occupation, ISCO-08**	**Age distribution**
		13,624								
		16,379								
		15,506								
Radnoff 2014 (Radnoff et al. 2014; Radnoff and Kutz 2014)	Construction (prevalence and level); Manufacturing (prevalence and level); Mining (prevalence and level); Electricity, gas, steam and air conditioning supply (prevalence and level)			Unclear	Canada	Region	Manual cement plant, sand and mineral, lime stone workers in Alberta, Canada			Unclear
		44						*24 Manufacture of basic metals*		
		23						*32 Other manufacturing*		
		28						*35 Electricity, gas, steam and air conditioning supply*		
		16						*23 Manufacture of other non-metallic mineral products*		
		78						*08 Other mining and quarrying*		
		44						*41 Construction of buildings*		
		24						*42 Civil engineering*		
		10						*43 Specialized construction activities*		
Rando 2001 (Rando et al. 2001)	Mining (level)	14,249		Unclear	United States of America	Region	Manual industrial sand workers in the United States of America	08 Other mining and quarrying	9311	Unclear
Rappaport 2003 (Rappaport et al. 2003)	Construction (prevalence and level); Professional, scientific and technical activities (level)			Unclear	United States of America	Region				Unclear
		14	*12*				*Painters in the United States of America construction industry*	*43 Specialized construction activities*	*7131*	
		11	*8*				*Bricklayers in the United States of America construction industry*	*43 Specialized construction activities*	*7112*	
		46	*23*				*Engineers in the United States of America construction industry*	*71 Architectural and engineering activities; technical testing and analysis*	*3123*	
		80	*37*				*Construction workers in the United States of America construction industry*	*41 Construction of buildings*	*9313*	
Rees 1992 (Rees et al. 1992)	Manufacturing (prevalence)	12	43	Unclear	South Africa	Local	Manual pottery workers in South Africa	23 Manufacture of other non-metallic mineral products	7314	Unclear
Rokni 2016 (Rokni 2016)	Manufacturing (prevalence and level); Mining (prevalence and level)			Unclear	Iran (Islamic Republic of)	Region	Manual workers from different industries in Iran (Islamic Republic of)			83% between 20 and 40

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Table 2 (*continued*)

Study	Inclusion in *meta*-analyses?	Study population								
Study ID	**Industrial sector and estimate type**	**Number of measurements**	**Number of participants**	**Number of female participants**	**Country**	**Geographic location**	**Target population**	**Industrial sector, ISIC-4**	**Occupation, ISCO-08**	**Age distribution**
		12		*Unclear*			*Foundry workers in Iran (Islamic Republic of)*	*24 Manufacture of basic metals*	*8121*	
		12		*Unclear*			*Brick manufacturing workers in Iran (Islamic Republic of)*	*23 Manufacture of other non-metallic mineral products*	*9329*	
		12		*Unclear*			*Sand and gravel mining workers in Iran (Islamic Republic of)*	*08 Other mining and quarrying*	*8111*	
		12		*Unclear*			*Asphalt manufacturing workers in Iran (Islamic Republic of)*	*23 Manufacture of other non-metallic mineral products*	*8111*	
		12		*Unclear*			*Sandblasters in Iran*	*23 Manufacture of other non-metallic mineral products*	*8111*	
		12		*Unclear*			*Ceramic manufacturing workers in Iran*	*32 Other manufacturing*	*8111*	
		12		*Unclear*			*Stone cutters and millers in Iran*	*23 Manufacture of other non-metallic mineral products*	*7113*	
		12		*Unclear*			*Glass manufacturing workers in Iran*	*32 Other manufacturing*	*7315*	
Saiyed 1995 (Saiyed et al. 1995)	Manufacturing (prevalence)		292	Unclear	India	Region	Manual pottery workers in India	32 Other manufacturing	7314	Mean 33, SD 10.2
Sanderson 2000 (Sanderson et al. 2000)	Mining (prevalence and level)			Unclear	United States of America	Region	Manual industrial sand workers in the United States of America	08 Other mining and quarrying	9311	Unclear
		1278					*Industrial sand workers in the United States of America*			
		1299					*Industrial sand workers in the United States of America*			
		680					*Industrial sand workers in the United States of America*			
		1012					*Industrial sand workers in the United States of America*			
Sayler 2018 (Sayler et al. 2018)	Manufacturing (prevalence and level)	46		0	Thailand	Region	Manual stone processors in Thailand	*23 Manufacture of other non-metallic mineral products*	8112	Mean: 39, SD: 10
Scarselli 2014 (Scarselli et al. 2014)	Construction (level); Manufacturing (prevalence and level)			Unclear	Italy	National	Manual workers from different industries in Italy			Unclear
		315					*Manufacture nonmetallic mineral product workers in Italy*	*23 Manufacture of other non-metallic mineral products*		
		181					*Manufacture basic metal workers in Italy*	*24 Manufacture of basic metals*		
		217					*Manufacture furniture workers in Italy*	*31 Manufacture of furniture*		

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Study	Inclusion in *meta*-analyses?	Study population								
Study ID	Industrial sector and estimate type	Number of measurements	Number of participants	Number of female participants	Country	Geographic location	Target population	Industrial sector, ISIC-4	Occupation, ISCO-08	Age distribution
		505					*Construction workers in Italy*	*41 Construction of buildings*		
Siltanen 1976 (Siltanen et al. 1976)	Manufacturing (prevalence)	1,639	4,316	Unclear	Finland	National	Manual foundry workers in Finland	24 Manufacture of basic metals		Unclear
Swanepoel 2011 (Swanepoel et al. 2011; Swanepoel et al. 2018)	Crop and animal production (prevalence and level)	298		unclear	South Africa	Region	Manual Farmers in South Africa	01 Crop and animal production, hunting and related service activities		Unclear
Tavakol 2017 (Tavakol et al. 2017)	Construction (prevalence and level)	85		Unclear	Iran (Islamic Republic of)	National	Manual construction workers in Iran (Islamic Republic of)	41 Construction of buildings	9313; 3123	Mean 32
Ulvestad 2000 (Ulvestad et al. 2000)	Construction (prevalence and level)	339	193	0	Norway	National	Manual construction workers in Norway	42 Civil engineering	7119	Unclear
Ulvestad 2001a (Ulvestad et al. 2001a; Ulvestad et al. 2001b)	Construction (prevalence and level)	226	86	0	Norway	National	Manual construction workers in Norway	42 Civil engineering	7119	Unclear
van Deurssen 2014 (van Deurssen et al. 2014; van Deurssen et al. 2015)	Construction (prevalence and level)	149	116	0	Netherlands	Other	Manual construction workers in the Netherlands	41 Construction of buildings	9313	35–39 years
Verma 2014 (Verma et al. 2014)	Mining (prevalence and level)	277		Unclear	Canada	Local	Manual gold miners in Ontario, Canada	07 Mining of metal ores	8111	Unclear
Wang 2015 (Wang et al. 2015)	Manufacturing (prevalence)	2123	3129	Unclear	China	Region	Manual workers in different industries in China			Unclear
								20 Manufacture of chemicals and chemical products *23 Manufacture of other non-metallic mineral products* *25 Manufacture of fabricated metal products, except machinery and equipment* *27 Manufacture of electrical equipment* *24 Manufacture of basic metals* *32 Other manufacturing*		
Watts 2012 (Watts et al. 2012)	Mining (level)			Unclear	United States of America	National	Manual workers in different industries in the United States of America			Unclear

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Study Study ID	Inclusion in *meta*-analyses? Industrial sector and estimate type	Study population Number of measurements	Number of participants	Number of female participants	Country	Geographic location	Target population	Industrial sector, ISIC-4	Occupation, ISCO-08	Age distribution
		3025					*Metal mining workers in the United States of America*	*07 Mining of metal ores*	*9311*	
		1173		*Unclear*			*Metal mining workers in the United States of America*	*07 Mining of metal ores*	*9311*	
		10,674		*Unclear*			*Stone mine workers in the United States of America*	*08 Other mining and quarrying*	*9311*	
		5102		*Unclear*			*Stone mine workers in the United States of America*	*08 Other mining and quarrying*	*9311*	
		10,753		*Unclear*			*Crushed limestone workers in the United States of America*	*08 Other mining and quarrying*	*9311*	
		4711		*Unclear*			*Crushed limestone workers in the United States of America*	*08 Other mining and quarrying*	*9311*	
		16,560		*Unclear*			*Sand and gravel workers in the United States of America*	*08 Other mining and quarrying*	*9311*	
		6571		*Unclear*			*Sand and gravel workers in the United States of America*	*08 Other mining and quarrying*	*9311*	
		3412		*Unclear*	*United States of America*	*National*	*Nonmetal miners in the United States of America*	*08 Other mining and quarrying*	*9311*	*Unclear*
		1192		*Unclear*	*United States of America*	*National*	*Nonmetal miners in the United States of America*	*08 Other mining and quarrying*	*9311*	*Unclear*
Weeks 2006 (Weeks and Rose 2006)	Mining (prevalence and level)	16,207		Unclear	United States of America	National	Manual metal and non-metal minors in the United States of America	07 Mining of metal ores	9311	Unclear
Woskie 2002 (Woskie et al. 2002)	Construction (prevalence)	260		Unclear	United States of America	Unclear	Manual heavy and highway construction in the United States of America	43 Specialized construction activities	9313	Unclear
Yassin 2005 (Yassin et al. 2005)	Construction (level); Manufacturing (level); Mining (level)				United States of America		Manual workers from different industries in the United States of America			Unclear
		405		*Unclear*			*Stoner cutters in the United States of America*	*08 Other mining and quarrying*	*7113*	*Unclear*
		91		*Unclear*			*Tunnel construction workers in the United States of America*	*42 Civil engineering*	*7113*	*Unclear*
		1760		*Unclear*			*Iron foundries workers in United States of America*	*24 Manufacture of basic metals*	*8121*	*Unclear*
Yingratanasuk 2002 (Yingratanasuk et al. 2002)	Mining (prevalence)	148	97	33	Thailand	Local	Manual Stone Carvers in Thailand	08 Other mining and quarrying	7113	Mean 33
Zarei 2017 (Zarei et al. 2017)	Manufacturing (prevalence and level)	55		0	Iran (Islamic Republic of)	Local	Manual Foundry workers in Iran (Islamic Republic of)	24 Manufacture of basic metals	7214	Mean 32, SD 6.9

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Table 2 (*continued*)

Study Study ID	Inclusion in *meta*-analyses? Industrial sector and estimate type	Study population Number of measurements	Number of participants	Number of female participants	Country	Geographic location	Target population	Industrial sector, ISIC-4	Occupation, ISCO-08	Age distribution
Zhuang 2001 (Zhuang et al. 2001)	Manufacturing (prevalence and level); Mining (level)				China	National	Manual mine and pottery workers in China			Unclear
		56		*Unclear*			*Tungsten miners in China*	*07 Mining of metal ores*	*9311*	
		54		*Unclear*			*Pottery workers in China*	*23 Manufacture of other non-metallic mineral products*	*7314*	
		10		*Unclear*			*Tin miners in China*	*07 Mining of metal ores*	*9311*	
		23		*Unclear*			*Iron/copper miners in China*	*07 Mining of metal ores*	*9311*	

Study Study ID	Study type Study design	Study period	Exposure assessment Exposure definition	Unit for which exposure was assessed	Mode of exposure data collection	Exposure assessment methods	Type of exposure measure or estimate	Dates covered by exposure assessment (years)	Shortest and longest exposure period	Levels/ intensity of exposure	Potential co-exposure with other occupational risk factors
Andersson 2009 (Andersson et al. 2009; Andersson et al. 2012)	Measurement data from 1968 to 2006	1968–May 2006	Breathing zone respirable silica, mg/m^3. Exposed: Above LOQ	Individual level	Technical device for recent years; administrative records for past years. Adjustments made.	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1968–2006	Unclear	AM: 0.084 mg/m^3, Median: 0.030 mg/m^3, GM (GSD) 0.034 mg/m^3 (3.1)	Unclear
Archer 2002 (Archer et al. 2002)	Cross-sectional study	May–November 1999	Breathing zone respirable silica, mg/m^3, 4 h TWA. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1999	Unclear	AM (SD) 0.66 (1.56) mg/m^3	Unclear
Azari 2009 (Azari et al., 2009)	Cross-sectional study	Unclear	Breathing zone respirable silica, mg/m^3. Exposed: above lowest exposure category	Individual level	Technical device	Active filter sampling with cyclone, IAS	Prevalence	Unclear	Unclear		None
										Stone cutting and milling: GM 0.275 (95% CI 0.191 – 0.397) mg/m^3; Sand and gravel mining: GM 0.261 (95% CI 0.184 – 0.372) mg/m^3 Foundry work: 0.343 (0.231 – 0.510) mg/m^3 Asphalt preparation:	

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Table 2 (*continued*)

Study	Study type		Exposure assessment								
										0.267 (0.131 – 0.369) mg/m^3 Construction: 0.193 (0.124 – 0.301) mg/m^3 Unclear Sand blasting: GM 0.272 (95% CI 0.172 – 0.429) mg/m^3	
Bakke 2001 (Bakke et al. 2001)	Cross-sectional study	June 1996–July 1999	Breathing zone respirable silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1996–1999	Unclear	AM: 0.13 mg/m^3 GM (GSD) 0.035 (5.0)	VOC; Oil mist; Oil vapour; Formaldehyde; Nitrogen dioxide; Carbon monoxide; Carbon dioxide; Ammonia; Elemental carbon
Bakke 2014 (Bakke et al. 2014)	Case-control study	June 1996– July 1999	Breathing zone respirable silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling, X-ray diffraction	Prevalence	1996–1997	Unclear	AM: 0.127 mg/m^3. GM: 0.063 (GSD 3.3). 10–90 percentile 0.0016–0.267	Unclear
Carneiro 2017 (Carneiro et al. 2017)	Cross-sectional study	January 2006–November 2015	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	2006–2015	Unclear	AM 0.47 (95% C.I.0.39–0.61) mg/m^3. Range 0.07–2.3 mg/m3	Unclear
Chen 2012 (Chen et al. 2012)			Stationary measurements, total dust converted to respirable silica dust by a conversion factor. Exposure definition unclear	Group level	Technical device	Active filter sampling conversion factor from paired side-by-side measurements. Exposed: from numbers in the paper	Prevalence		Unclear		Unclear
	Measurement data from 1960 to 1980	*1960–1980*						*1960–1980*		*GM (GSD) 0.057 mg/m^3 (2.54)*	
	Measurement data from 1981 to 2000	*1981–2000*						*1981–2000*		*GM (GSD) 0.032 mg/m^3 (2.51)*	
	Measurement data from 1960 to 1980	*1960–1980*						*1960–1980*		*GM (GSD) 0.184 mg/m^3 (2.112)*	
	Measurement data from 1981 to 2000	*1981–2000*						*1981–2000*		*GM (GSD) 0.092 mg/m^3 (2.072)*	
Chen 2007 (Chen et al. 2007)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposure definition unclear	Group level	Technical device	Active filter sampling with cyclone, IS	Prevalence	Unclear	Unclear	0.22–0.68 mg/m^3	Unclear

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Study	Study type		Exposure assessment								
Churchyard 2004 (Churchyard et al. 2004)	Cross-sectional study	November 2000–March 2001	Breathing zone respirable crystalline silica, mg/m^3, 8 h TWA. Exposure definition:“90% of subjects between 0.029 and 0.075 mg/m3″	Group level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	2000	Unclear	AM (SD) 0.05 (0.72) mg/m^3. Range 0–0.71 mg/m^3	None
Dion 2005 (Dion et al. 2005)	Cross-sectional study	July 2000	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Group level	Technical device	Active filter sampling with cyclone, silica analysis method unclear	Prevalence	1999	Around 1 month	Below LOD – 0.16 mg/m^3	Cristobalite at much lower levels
Estellita 2010 (Estellita 2010)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence		Unclear		
										GM 0.1–0.2 mg/m^3	*Unclear*
										GM ND-0.1 mg/m^3	*Unclear*
Flanagan 2006 (Flanagan et al. 2006)	Cross-sectional study	1992–2002	Silica, mg/m^3. Exposure definition unclear	Individual level	Technical device	Active filter sampling, silica analysis method unclear	Other	1992–2002	Unclear	GM (GSD) 0.13 mg/m^3 (5.9)	None
Foreland 2008 (Føreland et al. 2008)	Cross-sectional study	November 2002–December 2003	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD.	Individual level	Technical device	Silica determined by standard methods e.g. NIOSH, 1998	Other	2002–2003	Unclear	GM: ND – 0.02 mg/m^3	Fibres, Crystalline Silica, Silicon Carbide and Sulphur Dioxide. Low levels
Fulekar 1999 (Fulekar 1999)	Cross-sectional study	Unclear	Breathing zone respirable dust in mg/m^3; percent quartz assessed. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, silica analysis unclear	Prevalence	Unclear	Unclear	AM 0.76 mg/m^3	Unclear
Galea 2016 (Galea et al. 2016)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposure definition unclear	Individual level	Technical device	Active filter sampling with cyclone, infrared spectroscopy and/or X-ray diffraction.	Prevalence	6 days	Unclear	GM (GDD) 0.03 mg/m^3 (2.59). Min -max: LOD – 0.24 mg/m^3	Unclear
Golbabaei 2004 (Golbabaei et al. 2004)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	Unclear	Unclear	AM 0.0050–0.057 mg/m^3	None
Gottesfeld 2015 (Gottesfeld et al. 2015)	Cross-sectional study	2014	Breathing zone respirable crystalline silica,	Individual level	Technical device	Active filter sampling with	Prevalence	2014	85 min – 7 h	AM (SD) 16.9 (8.7) mg/m^3	Unclear

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Table 2 (*continued*)

Study	Study type		Exposure assessment								
			mg/m^3. Exposed: above LOD			cyclone, X-ray diffraction					
Green 2008 (Green et al. 2008)	Cross-sectional study	April 2006	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Group level	Technical device	Active filter sampling with cyclone direct reading photometric monitors	Prevalence	2006	12h	AM 1.09 mg/m^3	Domestic PM2.5 concentration: 0.534 mg/m^3, Environmental respirable dust concentration: 0.161 mg/m3
Grove 2014 (Grové et al. 2014)	Cross-sectional study	After 2008	Breathing zone and area samples of respirable silica dust, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, silica analysis unclear	Prevalence	After 2008	8 h shift	AM (SD) 0.005.-0.242 (0–0.331) mg/m^3. Min-max 0.005–0.890 mg/m^3	Coal dust
Guenel 1989 (Guénel et al. 1989)			Before 1970: number of respirable particles/m^3. After 1970: Breathing zone respirable crystalline silica, mg/m^3. Exposed: Quartz identified in the sample	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence				
		1948–1980						*1968–1977*	*Unclear*	*Unclear*	*Unclear*
		1948–1980						*1968–1977*	*Unclear*	*Unclear*	*Unclear*
Hammond 2016 (Hammond et al. 2016)	Cross-sectional study	Unclear	Breathing zone Respirable Crystalline Silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	21 days	7 to 12 h	GM 0.0042–0.0092 mg/m^3. AM 0.0049–0.0108 mg/m^3. range ND-0.024 mg/m^3	Unclear
Hayumbu 2008 (Hayumbu et al. 2008)	Cross-sectional study	Unclear	Breathing zone Respirable Crystalline Silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	Unclear	8 h shift	AM 0.06–0.24 mg/m^3 Median 0.04–0.10 mg/m^3 range 0–6.9 mg/m^3	Unclear
Healy 2014 (Healy et al. 2014)	Cross-sectional study	3 years - unclear when	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	3 years - unclear when	30–375 min	GM 0.008–0.14 mg/m^3	Unclear
Hicks 2006 (Hicks and Yager 2006)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3, 8 h TWA. Exposed: Above TLV (0.025 mg/m^3)	Individual level	Technical device	Active filter sampling with cyclone, silica analysis unclear	Prevalence	Unclear	8–12 h	AM 0.048–0.23 mg/m^3	Unclear

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Table 2 (*continued*)

Study	Study type		Exposure assessment								
Huizer 2010 (Huizer et al. 2010)	Other non-randomized intervention study	2009–2010	Breathing zone respirable crystalline silica, mg/m^3. Exposed: crystalline silica idenfified in the sample	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	2009–2010	Unclear	Range ND – 0.049 mg/m^3	Unclear
Khoza 2012 (Khoza 2012)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	Unclear	3 workdays of 8 h	*AM (SD) 0.17 (0.31) mg/m*^{3}. *Min*-max *0.010–0.662 mg/m*^{3} *AM (SD) 0.022–0.656 (0.021–1.247) mg/m*^{3}. *Min*-max *009–5.772 mg/m*^{3} *AM (SD) 0.017 (1.013) mg/m*^{3}. *Min*-max *0.009–0.062 mg/m*^{3} *AM (SD) (0.084–0.269 (0.086–0.477) mg/m*^{3}. *Min-Max 0.009–0.355 mg/m*^{3} *AM (SD) 0.022–0.656 (0.021–1.247) mg/m*^{3}. *Min*-max *009–5.772 mg/m*^{3} *AM (SD) (0.084–0.269 (0.086–0.477) mg/m*^{3}. *Min-Max 0.009–0.355 mg/m*^{3}	Unclear
Kim 2002 (Kim et al. 2002)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	Unclear	Full-shift	AM 0.0065–0.0148 mg/m^3 (range 0.0005–0.0510 mg/m^3)	Unclear
Koo 2000 (Koo et al., 2000)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica,	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	Unclear	Unclear	GM (GSD) 0.023–0.079 mg/m^3	None

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Table 2 (*continued*)

Study	Study type		Exposure assessment								
			mg/m^3. Exposed: above LOD							(1.42–2.81). Min-max 0.006–0.147 mg/m^3	
Kreiss 1996 (Kreiss and Zhen 1996)	Cross-sectional study	1974–1982	Respirable silica, mg/m^3. Exposed: unclear	Individual level	Technical device	Active filter sampling, hard correction factor between respirable dust and silica, 12.3%	Prevalence	1974–1982	Unclear	AM (SD) 0.09 (0.12) mg/m^3	None
Kullman 1995 (Kullman et al. 1995)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	Unclear	Unclear	GM (GSD) 0.04–0.06 mg/m^3 (1.62–1.94)	Asbestos fibres
Lee 2014 (Lee 2014)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above TLV (0.025 mg/m^3)	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	Unclear	Unclear	GM 0.043 mg/m^3	Unclear
Linch 2002 (Linch 2002)	Cross-sectional study	1992–1998	Breathing zone respirable crystalline silica, mg/m^3 8-hour TWA. Exposed: above LOD	individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1992–1998	Unclear	Range ND – 10 mg/m^3	Unclear
Love 1997 (Love et al. 1997)	Cross-sectional study	1990	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	1990	Full-shift	AM 0.04–0.62 mg/m^3 Min-max 0.01–3.8 mg/m^3	Unclear
Love 1999 (Love et al. 1999)	Cross-sectional study	Before 1999	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, infrared spectro-scopy	Prevalence	Unclear	Full-shift	AM 0.04–0.62 mg/m^3 Min-max 0.01–0.75 mg/m^3	Unclear
Mamuya 2006 (Mamuya et al. 2006a; Mamuya et al. 2006b)	Cross-sectional study	January– August 2003 and July–August 2004	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	2003–2004	Full-shift	AM (SD) 0.62 (2.36) mg/m^3 GM (GSD) 0.022 mg/m^3 (6.68)	Unclear
Nieuwenhuijsen 1999 (Nieuwenhuijsen et al. 1999)	Cross-sectional study	April 1995–June 1996	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1995–1996	Unclear	Respirable dust levels AM 0.03–4.447 mg/m^3) GM (GSD) 0.05–1.65 mg/m^3 (1.65–11.81) 18.6% silica in the dust	endotoxin
Nij 2003 (Tjoe Nij et al. 2003; Tjoe Nij et al. 2004)	Cross-sectional study	November 1999–December 1999	Breathing zone respirable crystalline silica,	Individual level	Technical device	Active filter sampling with	Prevalence	1999	Full-shift	GM (GSD) 0.13 mg/m^3 (5.4). AM 0.4 mg/m^3. Min-	None

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Table 2 (*continued*)

Study	Study type		Exposure assessment								
			mg/m^3. Exposed: Above LOD			cyclone, X-ray diffraction				Max 0.0016–4.7 mg/m3	
Normohammadi 2016 (Normohammadi et al. 2016)	Cross-sectional study	April 2010–June 2011	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	2010–2011	Full-shift	AM (SD) 0.190 (0.138) mg/m^3. GM (GSD) 0.132 mg/m^3 (2.65)	Unclear
Omidianidost 2015 (Omidianidost et al. 2015; Omidianidost et al. 2016)	Cross-sectional study	Unclear	Breathing zone total silica, mg/m^3. Exposed: above LOD	Group level	Technical device	Active filter sampling, IS	Prevalence	Unclear	Unclear	AM (SD) 0.19 (0.08) mg/m^3	Unclear
Oudyk 1995 (Oudyk 1995)	Cross-sectional study	1983–1988	Breathing zone respirable crystalline silica, mg/m^3	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1983–1988	Unclear	AM 0.086 mg/m^3 GSD 2.95	Unclear
Pandey 2017 (Pandey 2017)	Cross-sectional study	2012–2014	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	2012–2014	Unclear	AM 0.77–6.25 mg/m^3. Min - max 0.027–8.3 mg/m^3	None
Peters 2017 (Peters et al. 2017)	*MeasurementMeasurement data from 1986 to 2014*	1986–2014	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction or IS	Prevalence	1986–2014	Unclear	AM 0.043 mg/m^3. GM (GSD) 0.011 mg/m^3 (4.52)	Unclear
		1986–1990								*AM 0.101 mg/m^3. GM (GSD) 0.037 mg/m^3 (4.06)*	
		1991–1995								*AM 0.054 mg/m^3. GM (GSD) 0.017 mg/m^3 (3.88)*	
		1996–2000								*AM 0.058 mg/m^3. GM (GSD) 0.016 mg/m^3 (4.03)*	
		2001–2005								*AM 0.031 mg/m^3. GM (GSD) 0.007 mg/m^3 (4.46)*	
		2006–2010								*AM 0.021 mg/m^3. GM (GSD) 0.006 mg/m^3 (3.78)*	
		2011–2015								*AM 0.016 mg/m^3. GM (GSD) 0.006 mg/m3 (3.3352)*	
Radnoff 2014a + 2014b (Radnoff et al. 2014)	Cross-sectional study	2009–2013	Breathing zone respirable crystalline silica,	Group level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	2009–2013	Unclear	GM (GSD) 0.007–0.010 mg/m^3 (1.60–2.51) Min-	Unclear

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Study	Study type		Exposure assessment								
			mg/m^3. Exposed: Above LOD							max: 0.003–1.7 mg/m^3	
										GM (GSD) 0.02 mg/m^3 (4.18)	
										GM (GSD) 0.02 mg/m^3 (7.48)	
										GM (GSD) 0.024 mg/m^3 (10.17)	
										GM (GSD) 0.09 mg/m^3 (2.51)	
										GM (GSD) 0.048 mg/m^3 (3.13)	
										GM (GSD) 0.055 mg/m^3 (2.79)	
										GM (GSD) 0.013 mg/m^3 (2.16)	
										GM (GSD) 0.027 mg/m^3 (1.56)	
Rando 2001 (Rando et al. 2001)	Cross-sectional study	1973– 1998	Breathing zone respirable crystalline silica, mg/m3. Exposed: Unclear	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1973–1998	Unclear	GM (GSD) 0.042 mg/m^3 (6.5)	Unclear
Rappaport 2003 (Rappaport et al. 2003)	Cross-sectional study	April 1992–October 2000	Breathing zone respirable crystalline silica, mg/m3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1992–2000	Unclear		Wet dust suppression
										Median (min–max) *0.32 (0.007–14.2) mg/m^3*	
										Median (min–max) *1.28 (0.26–26.2) mg/m^3*	*Wet dust suppression*
										Median (min–max) *0.075 (0.007–0.800) mg/m^3*	*Wet dust suppression*
										Median (min–max) *0.35 (0.007–5.9) mg/m^3*	*Wet dust suppression*
Rees 1992 (Rees et al. 1992)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	Unclear	Unclear	Median 0.06–0.4 mg/m^3	None
Rokni 2016 (Rokni 2016)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica,	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	Unclear	< 8 h		

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Study	Study type		Exposure assessment								
			mg/m3. Exposed: above LOD								
										AM (SD) 0.34 (0.11) mg/m^3	
										AM (SD) 0.19 (0.13) mg/m^3	
										AM (SD) 0.28 (0.10) mg/m^3	
										AM (SD) 0.24 (0.17) mg/m^3	
										AM (SD) 0.31 (0.18) mg/m^3	
										AM (SD) 0.17 (0.065) mg/m^3	
										AM (SD) 0.32 (0.12) mg/m^3	
										AM (SD) 0.13 (009) mg/m^3	
Saiyed 1995 (Saiyed et al. 1995)	Cross-sectional study	Unclear	Stationary respirable crystalline silica, mg/m^3. Exposed: above LOD	Group level	Technical device	Active filter sampling, Pyro-phosphoric acid method for determining free silica	Prevalence	Unclear	Unclear	AM 0.019–8.28 mg/m^3	None
Sanderson 2000 (Sanderson et al. 2000)	Cross-sectional study		Breathing zone respirable crystalline silica, mg/m^3. Exposed: above 0.005 mg/m3).	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence		Unclear		Unclear
		1974–1979						*1974–1979*		*GM (GSD) 0.051 mg/m^3 (10.5)*	
		1980–1984						*1980–1984*	*Unclear*	*GM (GSD) 0.026 mg/m^3 (10.2)*	
		1985–1988						*1985–1988*	*Unclear*	*GM (GSD) 0.012 mg/m^3 (9.5)*	
		1989–1996						*1989–1996*	*Unclear*	*GM (GSD) 0.0075 mg/m^3 (9.1)*	
Sayler 2018 (Sayler et al. 2018)		May 2015	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	May 2015	Full-shift	AM 0.0059 mg/m3. GM (GSD) 0.0050 mg/mg^3 (1.7)	None
Scarselli 2014 (Scarselli et al. 2014)	Cross-sectional study	1996–2012	Breathing zone and area respirable crystalline silica, mg/m^3, 8 h TWA. Exposed: Above TLV (0.025 mg/m^3)	Individual level	Technical device	Unclear	Prevalence	1996–2012	Full-shift		Unclear
										AM 0.053 mg/m^3. GM (95%CI)	

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Table 2 (*continued*)

Study	Study type		Exposure assessment								
										0.017 (0.015–0.020) mg/m^3 GSD 4.203 AM 0.013 mg/m^3. GM (95%CI) 0.007 (0.006–0.008) mg/m^3 GSD 2.617 AM 0.037 mg/m^3. GM (95%CI) 0.01 (0.008–0.012) mg/m3 GSD 4.315 AM 0.057 mg/m^3. GM (95%CI) 0.045 (0.043–0.047) mg/m^3 GSD 1.707	
Siltanen 1976 (Siltanen et al. 1976)	Cross-sectional study	1972–1974	Breathing zone and area respirable crystalline silica, mg/m^3. Exposed: crystalline silica identified in the sample	Individual level	Technical device	Dust and crystalline silica was separated in ethyl alcohol by liquid sedimentation	Prevalence	1972–1974	2–8 h	AM 0.19–5.26 mg/m^3. Median 0.13–2.10 mg/m^3	Unclear
Swanepoel 2011 (Swanepoel et al. 2011; Swanepoel et al. 2018)	Cross-sectional study	July 2006–November 2009	Breathing zone respirable crystalline silica, mg/m^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	2006–2009	Full-shift	AM 0.046 mg/m^3; GM (GDS) 0.031 mg/mg (2.3)	None
Tavakol 2017 (Tavakol et al. 2017)	Cross-sectional study	Unclear	Breathing zone respirable crystalline silica, mg/m^3. Exposed: unclear	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	Unclear	4 h	AM (SE) 0.13 mg/m^3 (0.019)	Unclear
Ulvestad 2000 (Ulvestad et al. 2000)	Cross-sectional study	1996–1999	Breathing zone respirable crystalline silica, mg/m^3. Unexposed: Outdoor construction workers	Group level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Other	1996–1999	Unclear	Tunnelling: AM 0.034 mg/m^3. Outdoor construction work: AM 0.003 mg/m^3	None
Ulvestad 2001 (Bakke et al. 2001; Ulvestad et al. 2001a)	Case-control study	1996–1999	Breathing zone respirable crystalline silica, mg/m^3. Unexposed: Outdoor	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Other	1996–1999	Unclear	Drillers: AM 0.044 mg/m3. Shotcreters: AM 0.019 mg/m^3; Outdoor	None

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Table 2 (*continued*)

Study	Study type		Exposure assessment								
			construction workers							workers: 0.003 mg/m^3	
van Deurssen 2014 (van Deurssen et al. 2014; van Deurssen et al. 2015)	Cross-sectional study	November 2011 and February 2012	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS and X-ray diffraction	Prevalence	2011–2012	Unclear	GM (GSD) 0.1 mg /m^3 (3.84) min–max 0.01–1.36 mg/m^3	unclear
Verma 2014 (Verma et al. 2014)	Cross-sectional study	1978–1979	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	Unclear	Full-shift	AM 0.08 mg/m^3, Median 0.04 mg/m^3, Min-max 0.01–0.85	Unclear
Wang 2015 (Wang et al. 2015)	Cross-sectional study	Unclear	Respirable dust with silica, concentration according to the national standard. Exposed: unclear - numbers from paper	Individual level	Technical device	Quantitative measurement	Other	Unclear	Unclear	Range 0.04 to 46.7 mg/m^3 respirable dust, silica content not measured	Unclear
										Unclear	
										Unclear	
										Unclear	
										Unclear	
										Unclear	
										Unclear	
Watts Jr 2012 (Watts et al. 2012)	Cross-sectional study		Breathing zone and area respirable crystalline silica, mg/m^3. Exposed: unclear	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence		Unclear		Unclear
		1993–2004						*1993–2004*		*GM (GSD) 0.039 mg/m^3, (2.71)*	
		2005–2010						*2005–2010*		*GM 0.037 mg/m^3, GSD 2.54*	
		1993–2004						*1993–2004*		*GM (GSD) 0.036 mg/m^3, (2.75)*	
		2005–2010						*2005–2010*		*GM (GSD) 0.035 mg/m^3, (2.58)*	
		1993–2004						*1993–2004*		*GM (GSD) 0.023 mg/m^3, (2.39)*	
		2005–2010						*2005–2010*		*GM (GSD) 0.021 mg/m^3, (2.36)*	
		1993–2004						*1993–2004*		*GM (GSD) 0.031 mg/m^3, (2.57)*	
		2005–2010						*2005–2010*		*GM (GSD) 0.029 mg/m^3, (2.47)*	
	Cross-sectional study	*1993–2004*						*1993–2004*		*GM (GSD) 0.037 mg/m^3, (2.70)*	
	Cross-sectional study	*2005–2010*						*2005–2010*		*GM (GSD) 0.032 mg/m^3, (2.53)*	

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Study	Study type		Exposure assessment								
Weeks 2006 (Weeks and Rose 2006)	Cross-sectional study	1998–2002	Breathing zone respirable crystalline silica, mg/m^3. Exposed: below 0.05 mg/m3	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1998–2002		AM 0.047 mg/m^3; GM 0.0272 mg/m^3	
Woskie 2002 (Woskie et al. 2002)	Cross-sectional study	June 1994– April 1999	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone, IS	Prevalence	1994–1999	Unclear	GM (GSD) 0.007–0.026 mg/m^3 (2.8.5.9)	Diesel particles
Yassin 2005 (Yassin et al. 2005)	Cross-sectional study		Breathing zone respirable crystalline silica, mg/m^3. Exposed: unclear	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence		Unclear		Unclear
		1988–2003						*1988–2003*		*GM (GSD) 0.091 mg/m^3 (2.601)*	
		1988–2003						*1988–2003*		*GM (GSD) 0.070 mg/m^3 (2.289)*	
		1988–2004						*1988–2003*	*Unclear*	*GM (GSD) 0.073 mg/m^3 (2.404)*	
Yingratanasuk 2002 (Yingratanasuk et al. 2002)	Cross-sectional study	March 2000–October 2000.	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Group level	Technical device	Active filter sampling with cyclone, IS	Prevalence	2000	Full-shift	AM 0.05–0.88 mg/m^3. 95% percentile 0.13–2.12 mg/m^3	Unclear
Zarei 2017 (Zarei et al. 2017)	Cross-sectional study	2015	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone IS	Prevalence	2015	Full-shift	AM (SE) 0.25 (0.05) mg/m^3, Min-max 0.05–2.40 mg/m^3	Formaldehyde, triethylamine
Zhuang 2001 (Zhuang et al. 2001)	Cross-sectional study	1988–1989	Breathing zone respirable crystalline silica, mg/m^3. Exposed: Unclear	Individual level	Technical device	Active filter sampling with cyclone, X-ray diffraction	Prevalence	1988–1989	From 2.3 to 7.5 h		Unclear
										AM 0.101 (SD 0.131) mg/m^3	
										AM (SD) 0.116 (0.199) mg/m^3	
										AM (SD) 0.10 (0.13–0.17) mg/m^3	
										AM (SD) 0.017 (0.004) mg/m^3	

Study Study ID	Prevalence estimate Prevalence estimate type	Definition of numerator population	Count in numerator	N of study participants in exposed group	Definition of denominator population (source population)	Count in denominator	Number of study participants in unexposed group	Point estimate
Andersson 2009 (Andersson et al. 2009; Andersson et al. 2012)	Prevalence	Exposed iron foundries workers in Sweden	2174	2174	Iron foundries workers in Sweden	2333	159	93%

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Table 2 (*continued*)

Study Study ID	Prevalence estimate Prevalence estimate type	Definition of numerator population	Count in numerator	N of study participants in exposed group	Definition of denominator population (source population)	Count in denominator	Number of study participants in unexposed group	Point estimate
Archer 2002 (Archer et al. 2002)	Prevalence	Exposed farm workers in North Caroline, the United States of America	34	34	Farm workers in North Caroline, the United States of America	37	3	92%
Azari 2009 (Azari et al. (2009))	Prevalence	Cumulative exposure to crystalline silica > 0.99 mg/m^3-year in included industries			Manual workers from various industries in Iran (Islamic Republic of)			
			32	*32*		*40*	*8*	*79%*
			16	*16*		*20*	*4*	*79%*
			16	*16*		*20*	*4*	*79%*
			16	*16*		*20*	*4*	*79%*
			63	*63*		*80*	*17*	*79%*
			11	*11*		*14*	*3*	*79%*
Bakke 2001 (Bakke et al. 2001)	Prevalence	Exposed tunnel construction workers in Norway	299	299	Tunnel construction workers in Norway	386	87	79%
Bakke 2014 (Bakke et al. 2014)	Prevalence	Exposed tunnel construction workers in Norway	151	151	Tunnel construction workers in Norway	162	11	93%
Carneiro 2017 (Carneiro et al. 2017)	Prevalence	Exposed stone craftsmen in Brazil	50	50	Stone craftsmen in Brazil	50	0	100%
Chen 2012 (Chen et al. 2012)	Prevalence							
		Exposed metal mine workers in China	*39,925*	*39,925*	*Metal mine workers in China*	*59,743*	*19,818*	*67%*
		Exposed metal mine workers in China	*39,925*	*39,925*	*Metal mine workers in China*	*59,743*	*19,818*	*67%*
		Exposed pottery workers in China	*9384*	*9384*	*Pottery workers in China*	*14,297*	*4913*	*66%*
		Exposed pottery workers in China	*9384*	*9384*	*Pottery workers in China*	*14,297*	*4913*	*66%*
Chen 2007 (Chen et al. 2007)	Prevalence	Exposed refractory workers in Taiwan, China	36	36	Refractory workers in Taiwan, China	64	0	56%
Churchyard 2004 (Churchyard et al. 2004)	Prevalence	Exposed goldminers in South Africa	112	112	Goldminers in South Africa	112	0	100%
Dion 2005 (Dion et al. 2005)	Prevalence	Exposed workers in granite mining in Canada	19	19	Workers in granite mining in Canada	28	9	68%
Estellita 2010 (Estellita 2010)								
	Prevalence	*Exposed granite shop workers in Brazil*	*73*	*73*	*Granite shop workers in Brazil*	*78*	*5*	*94%*
	Prevalence	*Exposed granite miners in Brazil*	*7*	*7*	*Granite miners in Brazil*	*14*	*7*	*50%*
Flanagan 2006 (Flanagan et al. 2006)	Prevalence	Exposed construction workers in the United States of America	Unclear	Unclear	Construction workers in the United States of America	1374	Unclear	
Foreland 2008 (Føreland et al. 2008)	Prevalence	Exposed silicon carbide workers in Norway	408	408	Silicon carbide workers in Norway	680	200	60%
Fulekar 1999 (Fulekar 1999)	Prevalence	Exposed quartz manufacturing industry workers in India	Unclear	Unclear	Quartz manufacturing industry workers in India	Unclear	0	100%
Galea 2016- (Galea et al. 2016)	Prevalence	Exposed tunnel workers in London, the United Kingdom of Great Britain and Northern Ireland	< 49	< 49	Tunnel workers in London, the United Kingdom of Great Britain and Northern Ireland	49	Unclear	< 100%
Golbabaei 2004 (Golbabaei et al. 2004)	Prevalence	Exposed stone quarry workers in Iran (Islamic Republic of)	60	60	Stone quarry workers in Iran (Islamic Republic of)	60	0	100%
Gottesfeld 2015 (Gottesfeld et al. 2015)	Prevalence	Exposed artisanal Small-Scale Gold Mining in United Republic of Tanzania	11	11	Artisanal Small-Scale Gold Mining in United Republic of Tanzania	11	0	100%
Green 2008 (Green et al. 2008)	Prevalence	Exposed workers in stone crushing sites in India	79	79	Workers in stone crushing sites in India	79	0	100%
Grove 2014 (Grové et al. 2014)	Prevalence	Exposed coal miners in South Africa	42	42	Coal miners in South Africa	42	0	100%
Guenel 1989 (Guénel et al. 1989)								
	Prevalence	*Exposed road workers in Denmark*	*80*	*80*	*Road workers in Denmark*	*87*	*7*	*91%*
	Prevalence	*Exposed stone cutters in Denmark*	*21*	*21*	*Stone cutters in Denmark*	*21*	*0*	*100%*

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Table 2 (*continued*)

Study	Prevalence estimate							
Study ID	**Prevalence estimate type**	**Definition of numerator population**	**Count in numerator**	**N of study participants in exposed group**	**Definition of denominator population (source population)**	**Count in denominator**	**Number of study participants in unexposed group**	**Point estimate**
Hammond 2016 (Hammond et al. 2016)	Prevalence	Exposed Asphalt Pavement Milling in the United States of America	38	38	Asphalt Pavement Milling in the United States of America	42	4	90%
Hayumbu 2008 (Hayumbu et al. 2008)	Prevalence	Exposed copper mine workers in Zambia	152	152	Copper mine workers in Zambia	203	51	75%
Healy 2014 (Healy et al. 2014)	Prevalence	Exposed stone-workers in Ireland	55	55	Stone-workers in Ireland	103	48	53%
Hicks 2006 (Hicks and Yager 2006)	Prevalence	Exposed coal power plant workers in the United States of America	66	66	Coal power plant workers in the United States of America	108	42	61%
Huizer 2010 (Huizer et al. 2010)	Prevalence	Exposed teachers and students in Bricklaying Vocational Training Centers in the Netherlands	10	10	Teachers and students in Bricklaying Vocational Training Centers in the Netherlands	22	12	45%
Khoza 2012 (Khoza 2012)	Prevalence				Non-mining industry workers in South Africa			
		Foundry workers exposed to silica dust in South Africa	*54*	*54*	*Foundry workers from South Africa*	*54*	*0*	*100%*
		Sandstone/sandblasting workers exposed to silica dust in South Africa	*95*	*95*	*Sandstone/sandblasting workers in South Africa*	*95*	*0*	*100%*
		Construction workers exposed to silica dust in South Africa	*49*	*49*	*Construction workers in South Africa*	*49*	*0*	*100%*
		Ceramics/potteries/refractories workers exposed to silica dust in South Africa	*108*	*108*	*Ceramics/potteries/refractories workers in South Africa*	*108*	*0*	*100%*
		Sandstone/sandblasting workers exposed to silica dust in South Africa	*95*	*95*	*Sandstone/sandblasting workers in South Africa*	*95*	*0*	*100%*
		Ceramics/potteries/refractories workers exposed to silica dust in South Africa	*108*	*108*	*Ceramics/potteries/refractories workers in South Africa*	*108*	*0*	*100%*
Kim 2002 (Kim et al. 2002)	Prevalence	Exposed dental technicians in the Republic of Korea	41	41	Dental technicians in the Republic of Korea	41	0	100%
Koo 2000 (Koo (2000)	Prevalence	Exposed foundry workers in the Republic of Korea	22	209	Foundry workers in the Republic of Korea	22	0	100%
Kreiss 1996 (Kreiss and Zhen 1996)	Prevalence	Exposed miners in Colorado, the United States of America	Unclear	Unclear	Miners in Colorado, the United States of America	484	Unclear	
Kullman 1995 (Kullman et al. 1995)	Prevalence	Exposed Workers in American stone mining and milling operations	196	196	Workers in American stone mining and milling operations	559	363	35%
Lee 2014 (Lee 2014)	Prevalence	Exposed stone workers in the construction industry in the Republic of Korea	10	10	Stone workers in the construction industry in the Republic of Korea	14	4	71%
Linch 2002 (Linch 2002)	Prevalence	Exposed construction workers in the United States of America	23	23	Construction workers in the United States of America	45	22	49%
Love 1997 (Love et al. 1997)	Prevalence	Exposed worker in opencast coalmining in the United Kingdom of Great Britain and Northern Ireland	626	626	Workers in opencast coalmining in the United Kingdom of Great Britain and Northern Ireland	626	0	100%
Love 1999 (Love et al. 1999)	Prevalence	Exposed worker in the clay industry in the United Kingdom of Great Britain and Northern Ireland	1360	1360	Worker in the clay industry in the United Kingdom of Great Britain and Northern Ireland	1403	43	97%
Mamuya 2006 (Mamuya et al. 2006a; Mamuya et al. 2006b)	Prevalence	Exposed coal miners in the United Republic of Tanzania	147	147	Coal miners in the United Republic of Tanzania	173	26	85%
Nieuwenhuijsen 1999 (Nieuwenhuijsen et al. 1999)	Prevalence	Exposed farmers in California, the United States of America	72	72	Farmers in California, the United States of America	144	72	50%
Nij 2003 (Tjoe Nij et al. 2003; Tjoe Nij et al. 2004)	Prevalence	Construction workers in the Netherlands exposed to respirable quartz	57	57	Construction workers in the Netherlands	4	61	93%
Normohammadi 2016 (Normohammadi et al. 2016)	Prevalence	Exposed demolition workers in Iran (Islamic Republic of)	60	60	Demolition workers in Iran (Islamic Republic of)	60	0	100%

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Table 2 (*continued*)

Study	Prevalence estimate							
Study ID	**Prevalence estimate type**	**Definition of numerator population**	**Count in numerator**	**N of study participants in exposed group**	**Definition of denominator population (source population)**	**Count in denominator**	**Number of study participants in unexposed group**	**Point estimate**
Omidianidost 2015 (Omidianidost et al. 2015; Omidianidost et al. 2016)	Prevalence	Exposed foundry workers in Iran (Islamic Republic of)	80	80	Foundry workers in Iran (Islamic Republic of)	80	0	100%
Oudyk 1995 (Oudyk 1995)	Prevalence	Exposed ferrous foundries workers in Ontario, Canada	862	862	Ferrous foundries workers in Ontario, Canada	1038	176	83%
Pandey 2017 (Pandey 2017)	Prevalence	Exposed coal miners in Jharia, India	69	69	Coal miners in Jharia, India	69	0	100%
Peters 2017 (Peters et al. 2017)	Prevalence	Exposed miners in Australia	46,873	46,873	Miners in Australia	79,445	32,572	
			9976	*9976*		*11,084*	*1108*	*90%*
			11,895	*11,895*		*13,672*	*1777*	*87%*
			7987	*7987*		*9180*	*1193*	*87%*
			4496	*4496*		*13,624*	*9128*	*33%*
			6060	*6060*		*16,379*	*10,319*	*37%*
			6668	*6668*		*15,506*	*8838*	*43%*
Radnoff 2014 (Radnoff et al. 2014; Radnoff and Kutz 2014)	Prevalence	Exposed cement plant, sand and mineral, lime stone workers in Alberta, Canada			Cement plant, sand and mineral, lime stone workers in Alberta, Canada			
			38	*38*		*44*	*6*	*86%*
			18	*18*		*23*	*5*	*78%*
			22	*22*		*28*	*6*	*79%*
			16	*16*		*16*	*0*	*100%*
			56	*56*		*78*	*22*	*72%*
			43	*43*		*44*	*1*	*98%*
			22	*22*		*24*	*2*	*92%*
			10	*10*		*10*	*0*	*100%*
Rando 2001 (Rando et al. 2001)	Prevalence	Exposed industrial sand workers in the United States of America	Unclear	Unclear	Industrial sand workers in the United States of America	Unclear	Unclear	
Rappaport 2003 (Rappaport et al. 2003)	Prevalence							
		Exposed painters in the United States of America construction industry	*13*	*13*	*Painters in the United States of America construction industry*	*14*	*2*	*86%*
	Prevalence	*Exposed bricklayers in the United States of America construction industry*	*7*	*7*	*Bricklayers in the United States of America construction industry*	*11*	*4*	*64%*
	Prevalence	*Exposed engineers in the United States of America construction industry*	*34*	*34*	*Engineers in the United States of America construction industry*	*46*	*12*	*74%*
	Prevalence	*Exposed construction workers in the United States of America construction industry*	*68*	*68*	*Construction workers in the United States of America construction industry*	*80*	*12*	*85%*
Rees 1992 (Rees et al. 1992)	Prevalence	Exposed pottery workers in South Africa	12	12	Pottery workers in South Africa	12	0	100%
Rokni 2016 (Rokni 2016)	Prevalence							
		Exposed foundry workers in Iran (Islamic Republic of)	*12*	*12*	*Foundry workers in Iran (Islamic Republic of)*	*12*	*0*	*100%*
		Exposed brick manufacturing workers in Iran (Islamic Republic of)	*12*	*12*	*Brick manufacturing workers in Iran (Islamic Republic of)*	*12*	*0*	*100%*
		Exposed sand and gravel mining workers in Iran (Islamic Republic of)	*12*	*12*	*Sand and gravel mining workers in Iran (Islamic Republic of)*	*12*	*0*	*100%*
		Exposed asphalt manufacturing workers in Iran (Islamic Republic of)	*12*	*12*	*Asphalt manufacturing workers in Iran (Islamic Republic of)*	*12*	*0*	*100%*
		Exposed sandblasters in Iran (Islamic Republic of)	*12*	*12*	*Sandblasters in Iran (Islamic Republic of)*	*12*	*0*	*100%*
		Exposed ceramic manufacturing workers in Iran (Islamic Republic of)	*12*	*12*	*Ceramic manufacturing workers in Iran (Islamic Republic of)*	*12*	*0*	*100%*

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Table 2 (*continued*)

Study Study ID	Prevalence estimate Prevalence estimate type	Definition of numerator population	Count in numerator	N of study participants in exposed group	Definition of denominator population (source population)	Count in denominator	Number of study participants in unexposed group	Point estimate
		Exposed stone cutters and millers in Iran (Islamic Republic of)	*12*	*12*	*Stone cutters and millers in Iran (Islamic Republic of)*	*12*	*0*	*100%*
		Exposed glass manufacturing workers in Iran (Islamic Republic of)	*12*	*12*	*Glass manufacturing workers in Iran (Islamic Republic of)*	*12*	*0*	*100%*
Saiyed 1995 (Saiyed et al. 1995)	Prevalence	Exposed pottery workers in India	292	292	Workers in Indian potteries	292	0	100%
Sanderson 2000 (Sanderson et al. 2000)	Prevalence							
		Exposed industrial sand workers in the United States of America	*728*	*728*	*Industrial sand workers in the United States of America*	*1278*	*550*	*57%*
	Prevalence	*Exposed industrial sand workers in the United States of America*	*740*	*740*	*Industrial sand workers in the United States of America*	*1299*	*559*	*57%*
	Prevalence	*Exposed industrial sand workers in the United States of America*	*306*	*306*	*Industrial sand workers in the United States of America*	*680*	*374*	*45%*
	Prevalence	*Exposed industrial sand workers in the United States of America*	*385*	*385*	*Industrial sand workers in the United States of America*	*1012*	*627*	*38%*
Sayler 2018 (Sayler et al. 2018)	Prevalence	Exposed stone processors in Thailand	18	18	Stone processors in Thailand	46	28	40%
Scarselli 2014 (Scarselli et al. 2014)	Prevalence							
		Exposed manufacture of nonmetallic mineral product workers in Italy	*49*	*49*	*Manufacture nonmetallic mineral product workers in Italy*	*315*	*266*	*16%*
		Exposed manufacture of basic metal workers in Italy	*21*	*21*	*Manufacture of basic metal workers in Italy*	*181*	*160*	*12%*
		Exposed manufacture of furniture workers in Italy	*39*	*39*	*Manufacture of furniture workers in Italy*	*217*	*178*	*18%*
		Exposed construction workers in Italy	*471*	*471*	*Construction workers in Italy*	*505*	*34*	*93%*
Siltanen 1976 (Siltanen et al. 1976)	Prevalence	Exposed foundry workers in Finland	1608	1,608	Foundry workers in Finland	1639	21	98%
Swanepoel 2011 (Swanepoel et al. 2011; Swanepoel et al. 2018)	Prevalence	Exposed farmers in South Africa	176	176	Farmers in South Africa	298	122	59%
Tavakol 2017 (Tavakol et al. 2017)	Prevalence	Exposed construction workers in Iran (Islamic Republic of)	85	85	Construction workers in Iran (Islamic Republic of)	85	0	100%
Ulvestad 2000 (Ulvestad et al. 2000)	Prevalence	Exposed construction workers in Norway	302	302	Construction workers in Norway	339	37	89%
Ulvestad 2001 (Ulvestad et al. 2001a; Ulvestad et al. 2001b)	Prevalence	Exposed construction workers in Norway	158	158	Construction workers in Norway	226	68	70%
van Deurssen 2014 (van Deurssen et al. 2014; van Deurssen et al. 2015)	Prevalence	Exposed construction workers in the Netherlands	142	142	Construction workers in the Netherlands	149		95%
Verma 2014 (Verma et al. 2014)	Prevalence	Exposed gold miners in Ontario, Canada	252	252	Gold miners in Ontario, Canada	277	25	91%
Wang 2015 (Wang et al. 2015)	Prevalence	Exposed workers in the respective industries in China	302	302	All workers in all the respective industries in China	2123		
			Unclear	*Unclear*		*Unclear*	*Unclear*	*19%*
			Unclear	*Unclear*		*Unclear*	*Unclear*	*66%*
			Unclear	*Unclear*		*Unclear*	*Unclear*	*7%*
			Unclear	*Unclear*		*Unclear*	*Unclear*	*4%*
			Unclear	*Unclear*		*Unclear*	*Unclear*	*3%*
			Unclear	*Unclear*		*Unclear*	*Unclear*	*5%*
Watts Jr 2012 (Watts et al. 2012)	Prevalence							
		Exposed metal miners the United States of America	*Unclear*	*Unclear*	*Metal mining workers the United States of America*	*3025*	*Unclear*	

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Table 2 (*continued*)

Study Study ID	Prevalence estimate Prevalence estimate type	Definition of numerator population	Count in numerator	N of study participants in exposed group	Definition of denominator population (source population)	Count in denominator	Number of study participants in unexposed group	Point estimate
		Exposed metal miners the United States of America	*Unclear*	*Unclear*	*Metal mining workers the United States of America*	*1173*	*Unclear*	
		Exposed stone miners the United States of America	*Unclear*	*Unclear*	*Stone mine workers the United States of America*	*10,674*	*Unclear*	
		Exposed stone miners the United States of America	*Unclear*	*Unclear*	*Stone mine workers the United States of America*	*5102*	*Unclear*	
		Exposed crushed limestone workers in the United States of America	*Unclear*	*Unclear*	*Crushed limestone workers in the United States of America*	*10,753*	*Unclear*	
		Exposed crushed limestone workers in the United States of America	*Unclear*	*Unclear*	*Crushed limestone workers in the United States of America*	*4711*	*Unclear*	
		Exposed sand and gravel workers in the United States of America	*Unclear*	*Unclear*	*Sand and gravel workers in the United States of America*	*16,560*	*Unclear*	
		Exposed sand and gravel workers in the United States of America	*Unclear*	*Unclear*	*Sand and gravel workers in the United States of America*	*6571*	*Unclear*	
		Exposed nonmetal miners in the United States of America	*Unclear*	*Unclear*	*Nonmetal miners in the United States of America*	*3412*	*Unclear*	
		Exposed nonmetal miners in United States of America	*Unclear*	*Unclear*	*Nonmetal miners the United States of America*	*1192*	*Unclear*	
Weeks 2006 (Weeks and Rose 2006)	Prevalence	Exposed metal and nonmetal miners the United States of America	4408	4408	Metal and nonmetal miners the United States of America	16,207	11,799	27%
Woskie 2002 (Woskie et al. 2002)	Prevalence	Exposed heavy and highway construction the United States of America	246	246	Heavy and highway construction the United States of America	260	14	95%
Yassin 2005 (Yassin et al. 2005)	Prevalence							
		Exposed Stoner cutters the United States of America	*Unclear*	*Unclear*	*Stoner cutters the United States of America*	*406*	*Unclear*	
		Exposed tunnel construction workers the United States of America	*Unclear*	*Unclear*	*Tunnel construction workers the United States of America*	*91*	*Unclear*	
		Exposed iron foundries workers the United States of America	*Unclear*	*Unclear*	*Iron foundries workers the United States of America*	*1760*	*Unclear*	
Yingratanasuk 2002 (Yingratanasuk et al. 2002)	Prevalence	Exposed stone carvers in Thailand	148	148	Stone carvers in Thailand	148	0	100%
Zarei 2017 (Zarei et al. 2017)	Prevalence	Exposed foundry workers in Iran (Islamic Republic of)	55	55	Foundry workers in Iran (Islamic Republic of)	55	0	100%
Zhuang 2001 (Zhuang et al. 2001)	Prevalence		Unclear	Unclear	Unclear		Unclear	
		Exposed tungsten miners in China			*Tungsten miners in China*	*56*		
		Exposed pottery workers in China			*Pottery workers in China*	*54*		
		Exposed tin miners in China			*Tin miners in China*	*10*		
		Exposed iron/copper miners in China			*Iron/copper miners in China*	*23*		

Footnotes: AM: Arithmetic mean, SD: Standard deviation, GM: Geometric mean, GSD: Geometric standard deviation, LOD: level of detection, LOQ: level of quantification, IAS: infrared absorption spectroscopy, IS: infrared spectroscopy. Where a study includes two or more estimates/measures, the first entry in the table provides an overview of the information from the study. Estimate/measure-specific information is provided in subsequent linings, in italics.

agreement among them. Most data extractors participated in WHO's online training for the use of the data extraction sheet. At a minimum, two review authors independently extracted the data on occupational exposure to silica, asbestos or coal dust, disaggregated by country, sex, age and industrial sector and occupation. A third review author resolved conflicting extractions. Data were extracted on study characteristics (including study authors, study year, study country, participants and target population), study type (including study design and period) exposure assessment (including exposure definition, exposure assessment method, dates covered by the exposure assessment, and exposure level), prevalence estimate and study context. The estimates of exposure prevalences and levels from included studies were entered and managed with Microsoft Excel.

Data on potential conflict of interest were also extracted from the included studies, such as financial disclosures, funding sources, and authors' affiliated organization. A modification of a previous method was used to identify and assess undisclosed financial interests (Forsyth et al. 2014). If no financial disclosure and conflict of interest statements were provided, other records were searched from this study published in the 36 months prior to the included study record and in other publicly available repositories (Drazen et al. 2010b; Drazen et al. 2010a).

3.6. Requested missing data

Missing data were requested from the principal study author by email or phone, using the contact details provided in the principal study record. If no response was received at two weeks, a follow up email was sent. We requested silica data from six authors and silica and coal dust data from two authors. We received additional data on silica from two studies and additional coal dust data from one study. One author responded it was not possible to identify the data, and five authors did not respond (Appendix 2 in the Supplementary data).

3.7. Assessed risk of bias

We used the RoB-SPEO tool for assessing risk of bias in studies estimating exposure to occupational risk factors (Pega et al. 2020a), which has been validated in a recent study (Momen et al. 2022). WHO and ILO developed this tool specifically for their systematic reviews for the development of the WHO/ILO Joint Estimates (Pega et al. 2022c). For each included study, two or more review authors independently assessed risk of bias with RoB-SPEO, and another review author resolved any conflicts between the individual assessments.

3.8. Synthesised evidence (including conducted meta-analysis)

If we found two or more studies with an eligible measure of the prevalence estimate and/or level of exposure, two or more review authors independently assessed the heterogeneity (Deeks et al. 2011) of the studies in terms of population (WHO region and/or distribution by sex, age, industrial sector and occupation) and exposure (definition, measurement methods and level of exposure) following our protocol (Mandrioli et al. 2018). If we judged two or more measures of the prevalence or level of occupational exposure to be sufficiently homogenous, we pooled them in a quantitative *meta*-analysis, using the inverse variance method with a random effects model. We assessed statistical heterogeneity using the I^2 statistic, judging with QoE-SPEO (Pega et al. 2022b) a priori that the expected heterogeneity was moderate.

The *meta*-analyses for prevalence were conducted in MetaXL (Epigear) using double arcsine transformation, which has been recommended in *meta*-analyses of prevalence (Barendregt et al. 2013). The number of measurements indicating exposure and total number of measurements in the study were entered into MetaXL. The *meta*-analyses for level were conducted using the statistical software RevMan version 5.4.1 (Nordic Cochrane Centre) and forest plots were produced. It was evident from our search that the vast majority of studies were identified within certain industrial sectors or groupings thereof (Mining, Manufacture and Construction). Apart from that only a limited number of other industrial sectors were represented. We therefore synthesised evidence per industrial sector (ISIC-4 code at 2-digit level with additional merging within Mining, Manufacture and Construction) for prevalence and level of occupational exposure to silica, asbestos and coal dust, respectively.

All included data points from included studies are presented, together with *meta*-data on the study prevalence, and exposure level by country and industry.

Forest plots for prevalence were generated by inputting the denominator and numerator for each prevalence estimate into MetaXL. Studies reported several different measures of the level of exposure and its dispersion, such as arithmetic means and standard deviations, geometric means and geometric standard deviation factors, medians, ranges, 95% confidence intervals (CIs). It is well recognized that the distribution of data of concentrations are usually skewed and are therefore well represented by a log-normal function, and best summarised by geometric mean, geometric standard deviation factor and suitable CIs. We chose to use these measures to *meta*-analyse level of exposures. When they were not available from studies, we estimated them using the following formulae:

$$GM = \frac{AM}{\sqrt{1 + \frac{ASD^2}{AM^2}}}$$

$$GSD = exp\sqrt{ln\left(1 + \frac{ASD^2}{AM^2}\right)} GM = \exp\left(\frac{ln(a) + ln(b)}{2}\right)$$

$$GSD = exp\sqrt{2^{*}\ln\left(\frac{AM}{GM}\right)}$$

where GM and GSD are geometric mean and geometric standard deviation factor, AM and ASD are arithmetic mean and standard deviation, and (*a*) and (*b*) are the minimum and maximum values observed. Then, we calculated 95% CIs using the formula

$$Lower\ \ limit = \frac{GM}{(SE^{*})^{q}}$$

$$Upper\ \ limit = GM^{*}(SE^{*})^{q}$$

with $SE^{*} = (GSD)^{1/\sqrt{n}}$ and q is the 97.5% quantile of a t distribution with n-1 degrees of freedom.

To generate the forest plots, the estimates for geometric means were entered into RevMan to three decimal places. Additionally, the standard error, generated from the 95% CI that is most distant from the point estimate was entered to six decimal places.

3.9. Conducted additional analyses

We conducted subgroup analyses for mining, manufacture and construction (as here defined, and not as per ISIC classification) by WHO region based on disaggregated data from the studies included in the main *meta*-analysis only (to ensure a sufficiently homogenous dataset). We planned to also conduct subgroup analyses by sex, age group and occupation, but the data from included studies did not permit these analyses.

In a sensitivity analysis we compared studies we judged as at high or probably high risk of bias due to selection into the study with studies judged as at low or probably low risk of this bias.

3.10. Assessed quality of evidence

We used the QoE-SPEO approach for assessing the quality of

Table 3
Study and measurement numbers by industrial sector, for prevalence and level of occupational exposure to silica.

Industrial sector	Prevalence				Level			
	Number of entries and studies	Number of countries	Number of regions	Number of measurements	Number of entries and studies	Number of countries	Number of regions	Number of measurements
Construction	24 entries from 17 studies	7	4	2479	25 entries from 16 studies	8	4	2352
Manufacturing	39 entries from 24 studies	15	6	40,073	30 entries from 14 studies	10	6	7733
Mining	29 entries from 20 studies	13	6	222,276	43 entries from 17 studies	7	4	2,349,598
Crop and animal production	3 entries from 3 studies	2	2	479	2 entries from 2 studies	2	2	335
Electricity, gas and air supply	2 entries from 2 studies	2	1	136	1 entry from 1 study	2	1	28
Professional, scientific and technical activities	1 entry from 1 study	1	1	41	3 entries from 2 studies	2	2	18,313

evidence in studies estimating the prevalence and level of exposure to occupational risk factors (Pega et al. 2022b). QoE-SPEO was developed by WHO specifically for systematic reviews for the WHO/ILO Joint Estimates (Pega et al. 2022c).

We sought to ensure consistency in the assessment of quality of evidence with the other WHO/ILO systematic reviews of prevalences in the series for the WHO/ILO Joint Estimates (Hulshof et al. 2021a; Teixeira et al. 2021b), including downgrading for the serious concerns for indirectness presented by bodies of evidence without any included studies being population-based, i.e., covering the entire workers' population in the relevant industrial sector, including all its sub-sectors.

To assess publication bias for prevalence, Doi plots with LFK statistics (Furuya-Kanamori et al. 2018) were produced in MetaXL for each body of evidence comprising at least 10 study records. For levels, funnel plots were generated using RevMan.

4. Results

4.1. Study selection

A flow diagram of the study selection is presented in Fig. 1. Of a total of 13,329 unique individual study records identified in our searches, 100 records from 91 studies fulfilled the eligibility criteria and were included in the systematic review. For the 35 of the excluded studies that most closely resembled inclusion criteria, the reasons for exclusion are listed in Appendix 3 in the Supplementary data. The three most common reasons for exclusion were no quantitative exposure data reported (n = 95), ineligible setting (n = 114), and ineligible study type (n = 66). Of the 100 included records, 96 were included in one or more quantitative *meta*-analyses.

4.2. Characteristics of included studies

4.2.1. Occupational exposure to silica

The characteristics of all included studies relating to prevalence and level of occupational exposure to silica are summarize in Table 2.

In total, 65 studies from 73 study records that reported on occupational exposure to silica met the inclusion criteria. Of these, 55 studies described in 63 study records looked at silica prevalence. For silica level, there were 39 studies described in 46 study records. See Table 3 for a breakdown by industrial sector.

For silica, the target population was from major ISCO groups coded 3, 6, 7, 8 and 9 at the 1-digit level, and almost all measurements were performed among workers with manual work. Only three silica studies included measurements from administrative workers (Love et al. 1999; Rappaport et al. 2003; Peters et al. 2017). No included studies were population-based. Therefore, no included individual study captured all subsectors or the entire population of workers in the industrial sector of interest. Additionally, the body of evidence (i.e., all included studies together) also did not capture all subsectors within the relevant industrial sector, nor the entire workers' population within the industrial sector.

4.2.1.1. Study type. For silica, most studies were cross-sectional studies (50 out of 55 studies for prevalence and 34 out of 39 studies for level).

4.2.1.2. Population studied. For silica, the actual number of workers included in the studies may deviate from the number of measurements, i.e., nine of the studies were based on group-based estimates, and therefore the number of workers is underestimated. On the other hand, several studies included more than one measurement per person, and this overestimates the number of workers included.

Forty-four out of 65 included silica studies did not state the number of workers included, but only the number of measurements. Thus, the sum of workers indicated in Table 2 (161,634 workers) is far below the number of measurements (2,369,742). The sum of female workers indicated in Table 2 is 10,572, but the true proportion of males and females is unclear. Eight studies included male workers only, three studies included both male and female workers, and the rest (54 studies) did not provide any information about the gender distribution.

Most silica studies examined populations in the WHO Region of the Americas (21 studies from three countries), followed by populations in Europe (16 studies from eight countries) and populations in the Africa and Western Pacific (eight studies from three countries, and eight studies from four countries, respectively). The most commonly studied countries were the United States of America (15 studies), Iran (Islamic Republic of) (seven studies), Norway (five studies) and South Africa (five studies).

The industrial sectors most commonly studied for occupational exposure to silica were Other mining and quarrying (19 studies), Manufacture of other non-metallic mineral products (14 studies), and Manufacture of basic metals (12 studies). The occupations studied in most silica studies were "Mining and Quarrying Labourers" (15 studies), followed by "Building Construction Labourers" (10 studies) and "Miners and Quarries" and "Manufacturing Labourers Not Elsewhere Classified" (seven studies).

4.2.1.3. Exposure studied. All 65 included silica studies used active filter sampling and gravimetric assessment followed by technical analysis for quantification of silica. Sixty-two studies included personal air sampling, three studies stationary measurements, and four did not specify the sampling collection mode. Sixty-three studies assessed respirable crystalline silica, and two studies collected other particles size fractions. Thirty-three studies used X-ray diffraction for analysis of the silica

Table 4
Characteristics of included studies, Prevalence and level of occupational exposure to asbestos.

Study	Inclusion in *meta*-analyses?	Study population								
Study ID	Industrial sector and estimate type	Number of measurements	Number of participants	Number of female participants	Country	Geographic location	Target population	Industrial sector, ISIC-4	Occupation, ISCO-08	Age distribution
Ansari 2007 (Ansari et al. 2007)	Manufacturing (prevalence and level)		65	16	India	Local	Informal sector manual asbestos mill workers in India	23 Manufacture of other non-metallic mineral products	9329	Unclear
Bird 2004 (Bird et al. 2004)	Electricity, gas, steam and air conditioning supply (prevalence)	203	Unclear		United States of America	Region		35 Electricity, gas, steam and air conditioning supply	3131	Unclear
Borton 2012 (Borton et al. 2012)	Manufacturing (prevalence)	914	Unclear		United States of America	Local	Manual workers in a care product manufacturing company in Ohio, the United States of America	23 Manufacture of other non-metallic mineral products	9329	Unclear
Cattaneo 2012 (Cattaneo et al. 2012)	Other mining and quarrying (prevalence and level)	105	Unclear		Italy	Local	Manual quarries and stone processing workers in Italy	08 Other mining and quarrying	8111	Unclear
Damiran 2015 (Damiran et al. 2015)	Electricity, gas, steam and air conditioning supply (prevalence and level)	47	Unclear		Mongolia	Local	Manual special construction workers in Mongolia	35 Electricity, gas, steam and air conditioning supply	7124	Unclear
Kakooei 2007 (Kakooei et al. 2007)	Manufacturing (prevalence)	**75**	Unclear		Iran (Islamic Republic of)	Local	Brake manufacturing workers in Iran (Islamic Republic of)	30 Manufacture of other transport equipment	7231	Unclear
Kakooei 2014 (Kakooei and Normohammadi 2014)	Construction (prevalence and level)	45	Unclear		Iran (Islamic Republic of)	Local	Demolition workers in Iran (Islamic Republic of)	43 Specialized construction activities	7111	Unclear
Kauffer 2007 (Kauffer and Vincent 2007)	Construction (level); Manufacturing (level)		Unclear	Unclear	France	National	Manual workers from different industries in France			Unclear
		392					*Workers manufacturing non-metallic products in France*	*23 Manufacture of other non-metallic mineral products*		
		243					*Construction workers in France*	*41 Construction of buildings*		
		110					*Workers manufacturing basic metals in France*	*24 Manufacture of basic metals*		
		114					*Motor vehicles workers in France*	*29 Manufacture of motor vehicles, trailers and semi-trailers*		
		247					*Motor vehicles repair workers in France*	*45 Wholesale and retail trade and repair of motor vehicles and motorcycles*		
		15					*Textile workers in France*	*13 Manufacture of textiles*		
		239					*Construction workers in France*	*41 Construction of buildings*		
		41					*Motor vehicles repair workers in France*	*45 Wholesale and retail trade and repair of motor vehicles and motorcycles*		

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Table 4 (*continued*)

Study Study ID	Inclusion in *meta*-analyses? Industrial sector and estimate type	Study population Number of measurements	 Number of participants	 Number of female participants	 Country	 Geographic location	 Target population	 Industrial sector, ISIC-4	 Occupation, ISCO-08	 Age distribution
		1454					*Demolition workers in France*	*41 Construction of buildings*	*unclear*	
		982					*Construction workers in France*	*41 Construction of buildings*	*unclear*	
		79					*Construction (installation) workers in France*	*41 Construction of buildings*	*unclear*	
		111					*Construction (completion) workers in France*	*41 Construction of buildings*	*unclear*	
		1208					*Construction workers (erection of roofs) in France*	*43 Specialized construction activities*	*unclear*	
		65					*Construction workers (highways etc.) in France*	*43 Specialized construction activities*	*unclear*	
		6650					*Other construction workers in France*	*43 Specialized construction activities*	*unclear*	
		725					*Construction (insulation) workers in France*	*43 Specialized construction activities*	*unclear*	
		4507					*Sewage and sanitary workers in France*	*37 Sewerage*	*unclear*	
Maino 1995 (Maino et al. 1995)	Construction (prevalence and level)	32	Unclear		Italy	Region	Manual asbestos removal workers in Italy	43 Specialized construction activities	9313	Unclear
Marioryad 2011 (Marioryad et al. 2011)	Manufacturing (prevalence and level)	98	Unclear		Iran (Islamic Republic of)	Local	Manual asbestos cement workers in Iran (Islamic Republic of)	23 Manufacture of other non-metallic mineral products	8114	40–44 years
Massaro 2012 (Massaro et al. 2012)	Construction (prevalence and level)	368	Unclear	0	Italy	Region	Manual construction workers in Italy	43 Specialized construction activities		Unclear
		5	Unclear	0	Italy	Region	Manual construction workers in Italy	43 Specialized construction activities		Unclear
Mlynarek 1996 (Mlynarek et al. 1996)		302	Unclear	Unclear	United States of America	Local	Manual building maintenance workers in the United States of America	43 Specialized construction activities	9313	Unclear
Panahi 2011 (Panahi et al. 2011)	Manufacturing (prevalence and level)	45	120	0	Iran (Islamic Republic of)	Local	Manual asbestos cement sheet manufacturing workers in Iran (Islamic Republic of)	23 Manufacture of other non-metallic mineral products	7114	Mean age (range) 41 (29–56) years
Perkins 2008 (Perkins et al. 2008)	Construction (prevalence and level)	564	Unclear	Unclear	United States of America	Region	Manual road construction workers in the United States of America, natural occurring asbestos	43 Specialized construction activities	9313	Unclear
Phanprasit 2009 (Phanprasit et al. 2009)	Manufacturing (prevalence and level)	**19**	Unclear	Unclear	Thailand	Unclear	Manual asbestos cement sheet manufacturing workers in Thailand	23 Manufacture of other non-metallic mineral products	8114	Unclear
Scarselli 2016 (Scarselli et al. 2016)	Construction (prevalence and level); Water supply, sewerage, waste management and remediation (level)	2440	Unclear	Unclear	Italy	National		41 Construction of buildings		Unclear

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Table 4 (*continued*)

Study	Inclusion in *meta*-analyses?	Study population								
Study ID	Industrial sector and estimate type	Number of measurements	Number of participants	Number of female participants	Country	Geographic location	Target population	Industrial sector, ISIC-4	Occupation, ISCO-08	Age distribution
		8583						43 Specialized construction activities		
		4507						37 Sewerage		
Wang 2012 (Wang et al. 2012)	Manufacturing (prevalence)	32	Unclear	0	China	Unclear	Manual asbestos manufacturing workers in China	23 Manufacture of other non-metallic mineral products	Not applicable	Unclear
Wilmoth 1994 (Wilmoth 1994)	Construction (prevalence)	38	11	Unclear	United States of America	Local	Manual demolition workers in Alaska, the United States of America	43 Specialized construction activities	9313	Unclear

Study	Study type		Exposure assessment								
Study ID	Study design	Study period	Exposure definition	Unit for which exposure was assessed	Mode of exposure data collection	Exposure assessment methods	Type of exposure measure or estimate	Dates covered by exposure assessment (years)	Shortest and longest exposure period	Levels/ intensity of exposure	Potential co-exposure with other occupational-risk factors
Ahmad Ansari 2007 (Ansari et al. 2007)	Cross-sectional study	Unclear	Breathing zone asbestos fibres, f/cm^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling. Microscope membrane filter analysis	Prevalence	Unclear	Unclear	AM 2.24–15.6 f/ml	No
Bird 2004 (Bird et al. 2004)	Cross-sectional study	Unclear. June-August in 2001 or in 2002	Stationary sampling asbestos fibres, f/cm^3. Exposed: above LOD	Group level	Technical device	Active filter sampling, PCM	Prevalence	2001 or 2002	Unclear	Range LOD – 0.007 f/ml	Arsenic
Borton 2012 (Borton et al. 2012)	Cohort study (retrospective)	1972–1994	Breathing zone and area sampling asbestos fibres, f/cm^3. Exposed: above LOD or LOQ	Individual level	Technical device	Active filter sampling, PCM	Prevalence	Exposure measurements available 1972–1994	Unclear	GM 1992: 3.32 f/ml, GM 1996: 1.49 f/ml, GM 1997–1997: 0.03 f/ml	No
Cattaneo 2012 (Cattaneo et al. 2012)	Cross-sectional study	Unclear	Breathing zone and Stationary sampling asbestos fibres, f/cm3. Exposed: above LOD	Individual level	Technical device	Active filter sampling, SEM equipped with X-ray microanalysis.	Prevalence	Unclear	Unclear	AM (SD) 0.0500 (0.2275) f/ml. Median 0.0021 f/ml. Range 0.00005–1.8517 f/ml	Unclear
Damiran 2015 (Damiran et al. 2015)	Cross-sectional study	Unclear	Breathing zone and stationary sampling asbestos fibres, f/cm^3. Exposed: above LOD	Individual level	Technical device	Active filter sampling, PCM	Prevalence	Unclear	Unclear (Average sample time in table 1 might be exposure period.)	AM 0.96 f/ml	Unclear
Kakooei 2007 (Kakooei et al. 2007)	Cross-sectional study	2002	Breathing zone asbestos fibres, f/cm^3. Estimated from the total	Individual level	Technical device	Active filter sampling of total dust. PCOM	Prevalence	2012	30–60 min	AM between 0.36 and 1.85 f/ml, SD between 0.02 and 0.08 f/ml	Unclear

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Table 4 (*continued*)

Study	Study type		Exposure assessment								
Study ID	**Study design**	**Study period**	**Exposure definition**	**Unit for which exposure was assessed**	**Mode of exposure data collection**	**Exposure assessment methods**	**Type of exposure measure or estimate**	**Dates covered by exposure assessment (years)**	**Shortest and longest exposure period**	**Levels/ intensity of exposure**	**Potential co-exposure with other occupational-risk factors**
			dust fraction. Exposed: above LOD								
Kakooei 2014 (Kakooei and Normohammadi 2014)	Cross-sectional study	2010–2011	Breathing zone asbestos fibres, f/ cm^3. Estimated from the total dust fraction. Exposed: above LOD	Individual level	Technical device	Active filter sampling, PCOM and SEM)	Prevalence	2010–2011	240–360 min	PCM: GM (GSD) 0.07 f/ ml (0.339). Min-max 0.01–0.15 f/ml. SEM: GM (GSD) 0.20 f/ml (0.111). Min-max 0.02–0.36 f/ml	Unclear
Kauffer 2007 (Kauffer and Vincent 2007)	Cross-sectional study		Breathing zone and stationary sampling asbestos fibres, f/ cm^3. Various methods.	Individual level	Technical device	Active filter sampling. PCOM	Prevalence		Unclear		Unclear
		1986–1996						*1986–1996*		*AM 0.79 f/ml. Median 0.33 f/ml. Min-max 0.03–9.5 f/ml*	
		1986–1996						*1986–1996*		*AM 9.2 f/ml. Median 0.85 f/ml. Min-max 0.01–370 f/ml*	
		1986–1996						*1986–1996*		*AM 2.5 f/ml. Median 0.42 f/ml. Min-max 0.02–79 f/ml*	
		1986–1996						*1986–1996*		*AM 0.66 f/ml. Median 0.23 f/ml. Min-max 0.02–6.3 f/ml*	
		1986–1996						*1986–1996*		*AM 3.0 f/ml. Median 0.45 f/ml. Min-max 0.01–160 f/ml*	
		1986–1996						*1986–1996*		*AM 2.8 f/ml. Median 1.5 f/ml. Min-max 0.04–19 f/ml*	
		1997–2004						*1997–2004*		*AM 1.1 f/ml. Median 0.07 f/ml. Min-max 0.004–8.3 f/ml*	
		1997–2004						*1997–2004*		*AM 0.086 f/ml. Median 005 f/ml. Min-max 0.01–1.1 f/ml*	
										AM (SD) 0.005 (0.032) f/ml. GM (GSD) 0.003 f/ ml (2.31)	
										AM (SD) 0.010 (0.022) f/ml. GM (GSD) 0.004 f/ ml (3.76)	
										AM (SD) 0.017 (0.019 f/ ml. GM (GSD) 0.008 f/ ml (3.73)	

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Table 4 (*continued*)

Study	Study type		Exposure assessment								
Study ID	Study design	Study period	Exposure definition	Unit for which exposure was assessed	Mode of exposure data collection	Exposure assessment methods	Type of exposure measure or estimate	Dates covered by exposure assessment (years)	Shortest and longest exposure period	Levels/ intensity of exposure	Potential co-exposure with other occupational-risk factors
										AM (SD) 0.009 (0.022) f/ml. GM (GSD) 0.001 f/ml (16.63) *AM (SD) 0.045(0.155) f/ml. GM (GSD) 0.006 f/ml (11.30)* *AM (SD) 0.004 (0.001) f/ml. GM (GSD) 0.004 f/ml (1.07)* *AM (SD) 0.036 (0.090) f/ml. GM (GSD) 0.011 f/ml (5.63)* *AM (SD) 0.011 (0.018) f/cc. GM (GSD) 0.006 f/cc (3.24)* *AM (SD) 0.016 (0.089) f/ml. GM (GSD) 0.003 f/ml. (7.67)*	
Maino 1995 (Maino et al. 1995)	Cross-sectional study	1993–1994	Breathing zone and stationary sampling asbestos fibres, ff/l. Exposed: above LOD	Individual level	Technical device	Active filter sampling, PCOM	Prevalence	1993–1994	Unclear	64.15 ff/l	Unclear
Marioryad 2011 (Marioryad et al. 2011)	Cross-sectional study	Unclear	Breathing zone asbestos fibres, f/cm^3. Estimated from the total dust fraction. Exposed: above LOD	Individual level	Technical device	Active filter sampling, polarized light microscopy.	Prevalence	Unclear	60–240 min	AM (SD) 0.3 (0.16) f/ml. GM (GSD) 0.09 f/ml (0.11). Min - max 0.02–0.69 f/ml	Unclear
Massaro 2012 (Massaro et al. 2012)	Cross-sectional study	2008–2009	Stationary sampling asbestos fibres, ff/l. Exposed: above LOD	Individual level	Technical device	Active filter sampling, SEM and EDS micro-analysis	Prevalence	2008–2009	Unclear	Unclear	Unclear
	Cross-sectional study	2008–2009	Breathing zone asbestos fibres, ff/l. Exposed: above LOD	Individual level	Technical device	Active filter sampling, SEM and EDS micro-analysis	Prevalence	2008–2009	Unclear	6.034 ff/l	Unclear
Mlynarek 1996 (Mlynarek et al. 1996)	Cross-sectional study	1988–1993	Breathing zone asbestos fibres, f/cm^3. Estimated from the total dust fraction. 8-TWA	Individual level	Technical device	Active filter sampling, PCM	Prevalence	Unclear	5–477 min	AM between 0.003 and 0.042 f/ml SD between 0.0039 and 0.038 f/ml. Min max 0.0023–0.21f/ml	Unclear
Panahi 2011 (Panahi et al. 2011)	Cross-sectional study	2009–2010	Breathing zone asbestos fibres, f/cm^3. Estimated from the total	Individual level	Technical device	Active filter sampling, PCM	Prevalence	2009–2010	60 min	AM (SD) 0.0708 (0.05) f/ml GM (GDS) 0.052 f/ml(1.36) Min-max 0.012–0.243 f/ml	Unclear

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Table 4 (*continued*)

Study	Study type		Exposure assessment								
Study ID	**Study design**	**Study period**	**Exposure definition**	**Unit for which exposure was assessed**	**Mode of exposure data collection**	**Exposure assessment methods**	**Type of exposure measure or estimate**	**Dates covered by exposure assessment (years)**	**Shortest and longest exposure period**	**Levels/ intensity of exposure**	**Potential co-exposure with other occupational-risk factors**
			dust fraction. Exposed: above LOD								
Perkins 2008 (Perkins et al. 2008)	Cross-sectional study	Unclear	Breathing zone asbestos fibres, f/cm^3. Estimated from the total dust fraction. Exposed: above LOD	Individual level	Technical device	Active filter sampling, PCOM	Prevalence	Unclear	Unclear	371 samples above LOD, below 0.1 f/ml: AM (SD) 0.028 (0.016) f/ml 16 samples above LOD, Above 0.1 f/ml: AM (SD) 0.18 (0.12) f/ml	Unclear
Phanprasit 2009 (Phanprasit et al. 2009)	Cross-sectional study	2002	Breathing zone asbestos fibres, f/cm^3. Exposed: above 0.001f/cm^3	Individual level	Technical device	Active filter sampling, otherwise unclear	Prevalence	2002	Unclear	AM (SD) 0.078 (0.19) f/ml	unclear
Scarselli 2016 (Scarselli et al. 2016)	Cross-sectional study	1996–2013	Breathing zone asbestos fibres, f/cm^3. Estimated from the total dust fraction. Exposed: above LOD	Individual level	Technical device	Active filter sampling. PCOM and/or SEM	Prevalence	1996–2013	8 h work shift	GM (GSD) 0.001–0.008 f/ml (2.31–16.68) GM (GSD) 0.004–0.011 f/ml (1.07–11.3) GM (GSD) 0.003 f/ml (7.67)	Unclear
Wang 2012 (Wang et al. 2012)	Cross-sectional study	2002	Breathing zone and stationary sampling asbestos fibre, f/cm^3. Based on total dust samples. Exposed: above LOD	Individual level	Technical device	Active filter sampling, X-ray diffraction and TEM	Prevalence	2002	Full-shift	Personal sampling: median 4.5–8.6 f/ml (p25-p75 1.8–9.8 f/ml). Area sampling: median 0.8–7.2 f/ml (p25-p75 0.6–28.3 f/ml)	Unclear
Wilmoth 1994 (Wilmoth 1994)	Cross-sectional study	1992	Breathing zone asbestos fibres, f/cm^3. Estimated from the total dust fraction. 8-TWA. Exposed: above LOD	Individual level	Technical device	Active filter sampling, TEM	Prevalence	1992	60–208 min.	AM Below 0.033 f/ml	Unclear

Study	Prevalence estimate							
Study ID	**Prevalence estimate type**	**Definition of numerator population**	**Count in numerator**	**Number of study participants in exposed group**	**Definition of denominator population (source population)**	**Count in denominator**	**Number of study participants in unexposed group**	**Point estimate**

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Table 4 (*continued*)

Study	Prevalence estimate							
Study ID	**Prevalence estimate type**	**Definition of numerator population**	**Count in numerator**	**Number of study participants in exposed group**	**Definition of denominator population (source population)**	**Count in denominator**	**Number of study participants in unexposed group**	**Point estimate**
Ahmad Ansari 2007 (Ansari et al. 2007)	Prevalence	Exposed informal sector asbestos mill workers in India	Not applicable	65	Informal sector asbestos mill workers in India	Not applicable	0	100%
Bird 2004 (Bird et al. 2004)	Prevalence	Exposed power plant workers in the United States of America	4	4	Power plant workers in the United States of America	203	4	2%
Borton, 2012 (Borton et al. 2012)	Prevalence	Exposed workers of care product manufacturing in the United States of America	879	879	Workers of care product manufacturing in the United States of America	914	35	96%
Cattaneo, 2012 (Cattaneo et al. 2012)	Prevalence	Exposed quarries and stone processing workers in Italy	105 samples, number of persons unclear	89	Quarries and stone processing workers in Italy	105	16	85%
Damiran, 2015 (Damiran et al. 2015)	Prevalence	Exposed special construction workers in Mongolia	46	46	Special construction workers in Mongolia	47	1	98%
Kakooei, 2007 (Kakooei et al. 2007)	Prevalence	Exposed brake manufacturing workers in Iran (Islamic Republic of)	75	75	Brake manufacturing workers in Iran (Islamic Republic of)	75	0	100%
Kakooei, 2014 (Kakooei and Normohammadi 2014)	Prevalence	Exposed demolition workers in Iran (Islamic Republic of)	45	45	Demolition workers in Iran (Islamic Republic of)	45	0	100%
Kauffer, 2007 (Kauffer and Vincent 2007)	Prevalence		Unclear	Unclear			Unclear	Unclear
		Exposed workers manufacturing non-metallic products in France			*Workers manufacturing non-metallic products in France*	*392*		
		Exposed construction workers in France			*Construction workers in France*	*243*		
		Exposed workers manufacturing basic metals in France			*Workers manufacturing basic metals in France*	*110*		
		Exposed motor vehicles workers in France			*Motor vehicles workers in France*	*114*		
		Exposed motor vehicles repair workers in France			*Motor vehicles repair workers in France*	*247*		
		Exposed textile workers in France			*Textile workers in France*	*15*		
		Exposed construction workers in France			*Construction workers in France*	*239*		
		Exposed motor vehicles repair workers in France			*Motor vehicles repair workers in France*	*41*		
		Exposed demolition workers in France	*334*	*334*	*Demolition workers in France*	*1454*	*1120*	*23%*
		Exposed construction workers in France	*424*	*424*	*Construction workers in France*	*986*	*562*	*43%*
		Exposed construction (installation) workers in France			*Construction (installation) workers in France*	*79*		
		Exposed construction (completion) workers in France			*Construction (completion) workers in France*	*111*		
		Exposed construction workers (erection of roofs) in France	*604*	*604*	*Construct-ion workers (erection of roofs) in France*	*1208*	*604*	*50%*
		Exposed construction workers (highways etc.) in France			*Construction workers (highways etc.) in France*	*65*		
		Exposed other construction workers in France	*5187*	*5187*	*Other construction workers in France*	*6650*	*1463*	*78%*
		Exposed construction (insulation) workers in France	*326*	*326*	*Construction (insulation) workers in France*	*725*	*399*	*45%*
		Exposed sewage and sanitary workers in France	*2434*	*2434*	*Sewage and sanitary workers in France*	*4507*	*2073*	*54%*
Maino 1995 (Maino et al. 1995)	Prevalence	Exposed samples from environmental sampling	32	Not relevant	Total number of samples from environmental sampling	32	Not relevant	100%

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Table 4 (*continued*)

Study	Prevalence estimate							
Study ID	**Prevalence estimate type**	**Definition of numerator population**	**Count in numerator**	**Number of study participants in exposed group**	**Definition of denominator population (source population)**	**Count in denominator**	**Number of study participants in unexposed group**	**Point estimate**
Marioryad 2011 (Marioryad et al. 2011)	Prevalence	Exposed asbestos cement workers in Iran (Islamic Republic of)	98	98	Asbestos cement workers in Iran (Islamic Republic of)	98	0	100%
Massaro 2012 (Massaro et al. 2012)	Prevalence	Exposed construction workers in Italy	244	244	Construction workers in Italy	368	124	66%
	Prevalence	Exposed construction workers in Italy	5	5	Construction workers in Italy	5	0	100%
Mlynarek 1996 (Mlynarek et al. 1996)	Prevalence	Exposed building maintenance workers in the United States of America	Unclear	Unclear	Building maintenance workers in the United States of America	302	Unclear	Unclear
Panahi 2011 (Panahi et al. 2011)	Prevalence	Exposed asbestos cement sheet manufacturing workers in Iran (Islamic Republic of)	45	45	Asbestos cement sheet manufacturing workers in Iran (Islamic Republic of)	45	0	100%
Perkins 2008 (Perkins et al. 2008)	Prevalence	Exposed road construction workers in the United States of America, natural occurring asbestos	387	387	Road construction workers in the United States of America, natural occurring asbestos	564	177	69%
Phanprasit 2009 (Phanprasit et al. 2009)	Prevalence	Exposed asbestos cement workers in Thailand	15	15	Asbestos cement workers in Thailand	19	4	79%
Scarselli 2016 (Scarselli et al. 2016)	Prevalence							
		Exposed construction workers in Italy	758	758	Construction workers in Italy	2440	1682	31%
		Exposed construction workers in Italy	6117	6117	Construction workers in Italy	8583	2466	71%
		Exposed sewage workers in Italy	2434	2434	Sewage workers in Italy	4507	2073	54%
Wang 2012 (Wang et al. 2012)	Prevalence	Exposed asbestos manufacturing workers in China	32	32	Asbestos manufacturing workers in China	32	0	100%
Wilmoth 1994 (Wilmoth 1994)	Prevalence	Exposed demolition workers in Alaska, the United States of America	6	6	Demolition workers in Alaska, the United States of America	38	32	16%

Footnotes:

AM: Arithmetic mean, SD: Standard deviation, GM: Geometric mean, GSD: Geometric standard deviation, LOD: Level of detection, LOQ: Level of quantification, PCM: Phase contrast microscopy, PCOM: Phase-contrast optical microscopy, SEM: Scanning electron microscopy, TEM: Transmission electron microscopy.

Where a study includes two or more estimates/measures, the first entry in the table provides an overview of the information from the study. Estimate/measure-specific information is provided in subsequent linings, in italics.

Table 5
Study and measurement numbers by industrial sector for prevalence and level of occupational exposure to asbestos.

Industrial sector	Prevalence				Level			
	Number of entries and studies	Number of countries	Number of regions	Number of measurements	Number of entries and studies	Number of countries	Number of regions	Number of measurements
Construction	6	3	3	16,580	6	4	3	12,240
Manufacturing	7	5	4	1225	5	4	3	1431
Mining (other mining and quarrying)	1	1	1	89	1	1	1	89
Electricity, gas and air supply	2	2	2	108	1	1	1	46
Water supply, sewerage, waste management and remediation	NA	NA	NA	NA	1	1	1	4507

content, 18 studies used infrared spectrometry (IS), and 14 studies used other methods, or did not specify the method. In 41 studies, occupational exposure to silica was defined as silica measurements above the LOD, in six studies it was defines as above the occupational exposure limit (OEL), and in the remaining 18 studies it was defined in other ways or not specified. Fifty-five studies assessed exposure at an individual level, whereas in 10 studies measurements (personal or stationary) were used to express exposure at group level. In the vast majority of studies, 60, current exposure (prevalence) was assessed, and only five studies used other exposure metrics. Measurements between 1960 and 2014 were identified. Twenty-three studies included full-shift measurement (above 4 hours), four studies included measurements with a duration of $<$ 4 hours, and in the remaining 38 studies measurement duration was not specified. Forty-two studies presented a mean exposure level by AM (range 0.006–16.9 mg/m^3), 29 studies by GM (ND –1.65 mg/m^3), two studies by the median (range 0.075–1.3 mg/m^3), and eight studies by other or unclear methods. For 56 studies a prevalence estimate was available, ranging from 0.12 to 1.00.

4.2.2. Occupational exposure to asbestos

The characteristics of all included studies relating to prevalence and level of occupational exposure to asbestos are summarize in Table 4.

In total, 18 studies from 18 study records that reported on occupational exposure to asbestos met the inclusion criteria. Of these, 17 studies described in 17 study records provided information on asbestos prevalence. For asbestos level, 12 studies described in 12 study records provided information. See Table 5 for a breakdown by industrial sector.

The target population in all included studies was from major ISCO group 3, 7 and 9, and all measurements were performed among workers with manual work. No included studies were population-based. Therefore, no included individual study captured all subsectors or the entire population of workers in the industrial sector of interest. Additionally, the body of evidence (i.e., all included studies together) also did not capture all subsectors within the relevant industrial sector, nor the entire workers' population within the industrial sector.

4.2.2.1. Study type. For asbestos, most studies were cross-sectional (16 studies out of 17 for prevalence and all studies for level were cross-sectional).

4.2.3. Population studied

For asbestos the actual number of workers included in the studies may deviate from the number of measurements, i.e., one of the studies was based on group-based estimates, and therefore the number of workers is underestimated. On the other hand, several studies included more than one measurement per person, and this overestimates the number of workers included.

Thirteen of the included 18 asbestos studies did not state the number of workers included, but only the number of measurements. Thus, the sum of workers indicated in Table 4 (196 workers) is far below the number of measurements (35,604). The sum of female workers indicated in Table 4 is 16, but the true proportion of males and females is unclear. Three studies included male workers only, one study included both male and female workers, and the rest (14 studies) did not provide any information about the sex distribution.

Most asbestos studies examined populations in the Americas and Europe (five studies from one country, and five studies from two countries, respectively), followed by populations in the Eastern Mediterranean (four studies from one country). The most studied countries were the United States of America (five studies), Iran (Islamic Republic of) (four studies), and Italy (four studies). The most studied industrial sectors for occupational exposure to asbestos were Manufacture of other non-metallic mineral products (seven studies), Specialized construction activities (six studies), and Electricity, gas, steam and air conditioning supply (two studies).

The most studied occupations in asbestos studies were "Building Construction Labourers" (four studies), followed by "Cement, Stone and Other Mineral Products Machine Operators" (two studies) and "Manufacturing Labourers Not Elsewhere Classified" (two studies).

4.2.3.1. Exposure studied. All 18 included asbestos studies used active filter sampling and gravimetric assessment followed by technical analysis for quantification of asbestos fibres. Sixteen studies included personal air sampling, and six studies stationary measurements. Nine studies assessed asbestos fibres based on total dust, and the remaining nine studies did not specify the collected particle fraction. Ten studies used phase contrast microscopy for analysis of the content of asbestos fibres, five studies used scanning electron microscopy (SEM) or transmission electron microscopy (TEM), and three studies used other methods. In 13 studies, occupational exposure to asbestos was defined as asbestos fibres count above the LOD, and in the remaining five studies other definitions were used. Seventeen studies assessed exposure at an individual level and in one study stationary measurements were used to assess exposure at group level. All 18 studies assessed current exposure (prevalence). Measurements between 1972 and 2011 were identified. Five studies included full-shift measurement (above 4 hours), four studies included measurements with a duration below 4 hours, and in nine studies the sampling duration was unclear. Ten studies presented a mean exposure level by AM (range 0.03–16 f/ml), four studies by GM (range 0.03–3.2 f/ml), two studies by the median (range 0.002–8.6 f/ml), and four studies by other or unclear methods. For 15 studies a prevalence estimate was available, ranging from 0.02 to 1.00.

4.2.4. Occupational exposure to coal dust

The characteristics of all included studies relating to prevalence and level of occupational exposure to coal dust are summarize in Table 6.

In total, eight studies from nine study records that reported on occupational exposure to coal dust met the inclusion criteria. Of these, seven studies described in eight study records looked at coal dust prevalence. For coal dust level, four studies described in five study

Table 6
Characteristics of included studies, Prevalence and level of occupational exposure to coal dust.

Study ID	Industrial sector and estimate type	Number of measurements	Number of participants	Number of female participants	Country	Geographic location	Target population	Industrial sector, ISIC-4	Occupation, ISCO-08	Age distribution
Bird 2004 (Bird et al. 2004)	Electricity, gas, steam and air conditioning supply (prevalence and level)	203	Unclear	Unclear	United States of America	Region	Manual power plant workers in the United States of America	35 Electricity, gas, steam and air conditioning supply	3131	Unclear
Grove 2014 (Grové et al. 2014)	Mining of coal and lignite (prevalence)	42	Unclear	Unclear	South Africa	National	Manual coal miners in South Africa	05 Mining of coal and lignite	9311	Unclear
Love 1997 (Love et al. 1997)	Mining of coal and lignite (prevalence)	626	1249	25	United Kingdom of Great Britain and Northern Ireland	National	Manual workers in opencast coalmining in the United Kingdom of Great Britain and Northern Ireland	05 Mining of coal and lignite	9311	Unclear
Lu 2016 (Lu 2016)	Mining of coal and lignite (prevalence and level)	108	Unclear	Unclear	China	Local	Manual coal miners in China	05 Mining of coal and lignite	9311	Unclear
Mamuya 2006 (Mamuya et al. 2006a; Mamuya et al. 2006b)	Mining of coal and lignite (prevalence and level)	204	Unclear	0	United Republic of Tanzania	Region	Manual coal miners in the United Republic of Tanzania	05 Mining of coal and lignite	9311	Unclear
Piacitelli 1990 (Piacitelli et al. 1990)	Mining of coal and lignite (level)	99,220	Unclear	Unclear	United States of America	National	Manual surface coal miners in the United States of America	05 Mining of coal and lignite	8111	Unclear
Tripathy 2015 (Tripathy 2015)	Mining of coal and lignite (prevalence)	4	Unclear	Unclear	India	Region	Manual opencast coal miners in India	05 Mining of coal and lignite	8111	Unclear
Wang 2015 (Wang et al. 2015)	Mining of coal and lignite (prevalence)		2325	0	China	Region	Manual coal miners in China	05 Mining of coal and lignite	Unclear	Mean (SD) 36.7 (8.5) years

Study	Study type		Exposure assessment								
Study ID	**Study design**	**Study period**	**Exposure definition**	**Unit for which exposure was assessed**	**Mode of exposure data collection**	**Exposure assessment methods**	**Type of exposure measure or estimate**	**Dates covered by exposure ass. (years)**	**Shortest and longest exposure period**	**Levels/ intensity of exposure**	**Potential co-exposure with other occupational risk factors**
Bird 2004(Bird et al. 2004)	Cross-sectional study	June-August 2001 or 2002	Breathing zone respirable coal dust, mg/m3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone	Prevalence	2001 or 2002	Unclear	199 out of 203 measurements below LOD. Range below LOD – 5.3 mg/m3. Estimated overall mean below 0.3 mg/m3 coal dust	Arsenic, noise, heat stress
Grove 2014 (Grové et al. 2014)	Cross-sectional study	2006	Breathing zone and stationary sampling of respirable coal dust, mg/m3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone	Prevalence	After 2008	Full shift	AM 1.0–5.9 mg/m3 (min–max 0.9–9.2 mg/m3	Both coal dust and silica assessed

(continued on next page)

Table 6 (*continued*)

Study	Study type		Exposure assessment								
Study ID	Study design	Study period	Exposure definition	Unit for which exposure was assessed	Mode of exposure data collection	Exposure assessment methods	Type of exposure measure or estimate	Dates covered by exposure ass. (years)	Shortest and longest exposure period	Levels/ intensity of exposure	Potential co-exposure with other occupational risk factors
Love 1997 (Love et al. 1997)	Cross-sectional study	1990	Breathing zone respirable mixed dust, mg/m3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone	Prevalence	Unclear	Full shift	Range 0.02–20.1 mg/m3	Unclear
Lu 2016 (Lu 2016)	Cross-sectional study	2014	Stationary respirable coal dust, mg/m3. Exposed: Above LOD	Group level	Technical device	Area sampling with DUSTTRAK	Prevalence	2014	Unclear	AM (SD) 3.02–3.23 (2.34–2.67) mg/m3	Other metals and metalloids in coal dust assessed (Fe, Cu, Zn, Mn, Pb, Ni, Cd, and As): Microbiological exposure assessed
Mamuya 2006 (Mamuya et al. 2006a; Mamuya et al. 2006b)	Cross-sectional study	2003–2004	Breathing zone respirable coal dust, mg/m3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling with cyclone	Prevalence	2003–2004	5–10*h*	GM (GSD) 0.56 mg/m3 (5.37) Range 0.08–10.30 mg/m3	Unclear
Piacitelli 1990 (Piacitelli et al. 1990)	Cross-sectional study	1982–1986	Breathing zone respirable coal dust, mg/m3. Exposed: Above LOD	Group level	Technical device	Active filter sampling with cyclone	Prevalence	1980–1986	Unclear	AM (SD) 0.6–0.7 (1.1–1.7) mg/m3	Unclear
Tripathy 2015 (Tripathy 2015)	Cross-sectional study	Unclear	Breathing zone PM10 Coal dust, mg/m3. Exposed: Above LOD	Individual level	Technical device	Active filter sampling	Prevalence	Unclear	Unclear	Range 4.6–29.5 mg/m3	Unclear
Wang 2015 (Wang et al. 2015)	Cross-sectional study	2013	Coal dust, mg/m3. Exposure definition unclear	Unclear	Technical device	Active filter sampling	Prevalence	2013	Unclear	AM 1.18–6.96 mg/m3	Unclear

Study	Prevalence estimate							
Study ID	Prevalence estimate type	Definition of numerator population	Count in numerator	Number of study participants in exposed group	Definition of denominator population (source population)	Count in denominator	Number of study participants in unexposed group	Point estimate
Bird 2004 (Bird et al. 2004)	Prevalence	Exposed power plant workers in the United States of America	4	4	Power plant workers in United States of America	203	199	2%
Grove 2014 (Grové et al. 2014)	Prevalence	Exposed coal miners in South Africa	42	42	Coal miners in South Africa	42	0	100%
Love 1997 (Love et al. 1997)	Prevalence	Exposed worker in opencast coalmining in the United Kingdom of Great Britain and Northern Ireland	626	626	Workers in opencast coalmining in the United Kingdom of Great Britain and Northern Ireland	626	0	100%
Lu 2016 (Lu 2016)	Prevalence	Exposed coal miners in China	108	108	Coal miners in China	Unclear	0	100%
Mamuya 2006 (Mamuya et al. 2006a; Mamuya et al. 2006b)	Prevalence	Exposed coal miners in the United Republic of Tanzania	203	203	Coal miners in the United Republic of Tanzania	204	1	99%

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Table 6 (*continued*)

Study	Prevalence estimate							
Study ID	**Prevalence estimate type**	**Definition of numerator population**	**Count in numerator**	**Number of study participants in exposed group**	**Definition of denominator population (source population)**	**Count in denominator**	**Number of study participants in unexposed group**	**Point estimate**
Piacitelli 1990 (Piacitelli et al. 1990)	Prevalence	Exposed surface coal miners in the United States of America			Surface coal miners in the United States of America	99,220		
Tripathy 2015 (Tripathy 2015)	Prevalence	Exposed opencast coal miners in India	4	4	Opencast coal miners in India	4	0	100%
Wang 2015 (Wang et al. 2015)	Prevalence	Exposed coal miners in China	2325	2325	Coal miners in China	2325	0	100%

Footnotes:
AM: Arithmetic mean, SD: Standard deviation, GM: Geometric mean, GSD: Geometric standard deviation, LOD: level of detection, LOQ: level of quantification.
Where a study includes two or more estimates/measures, the first entry in the table provides an overview of the information from the study. Estimate/measure-specific information is provided in subsequent linings, in italics.

records met the inclusion criteria. See Table 7 for a breakdown by industrial sector.

The target population in all included studies was from major ISCO group 3, 7 and 9, and all measurements were performed among workers with manual work. No individual included study was population-based. For the industrial sector of Mining of coal and lignite (ISIC 05), we judged the body of evidence to probably capture all (or the great majority of) the industrial subsectors. For all other industrial sectors, all included studies collectively did not capture all industrial subsectors within the industrial sectors, and the respective body of evidence (i.e., all included studies together) also did not capture the entirety of the industrial sectors.

4.2.4.1. Study type. For coal dust, all studies for both prevalence and level were cross-sectional.

4.2.5. Population studied

For coal dust the actual number of workers included in the studies may deviate from the number of measurements, i.e., two of the studies were based on group-based estimates, and therefore the number of workers is underestimated. On the other hand, several studies included more than one measurement per person, and this overestimates the number of workers included.

Six of the included eight coal dust studies did not state the number of workers included, but only the number of measurements. Thus, the sum of workers indicated in Table 6 (3574) is far below the number of measurements (100,407). The sum of female workers indicated in Table 6 is 25, but the true proportion of males and females is unclear. Two studies included male workers only, one study included both male and female workers, and the rest (five studies) did not provide any information about the sex distribution.

Most coal dust studies examined populations in the Africa and Western Pacific (two studies from two countries, and two studies from one country, respectively). The most commonly studied countries were the People's Republic of China (two studies) and the United States of America (two studies). The most studied industrial sector for occupational exposure to coal dust was Mining of coal and lignite (seven studies). One study was conducted in the Electricity, gas, steam and air conditioning supply industry. The occupations studied in most coal dust studies were "Mining and Quarrying Labourers" (four studies), followed by "Miners and Quarries" (two studies) and "Power Production Plant Operators" (one study).

4.2.6. Exposure studied

All eight included coal dust studies used active filter sampling and gravimetric assessment of coal dust. Five studies included personal air sampling, two studies stationary measurements, and one study didn't specify the collection method. Five studies assessed respirable coal dust, two studies other particle size fractions, and one study did not define the collected particle fraction. In seven studies, occupational exposure to coal dust was defined as coal dust measurements above the LOD, in one study the definition was unclear. Five studies assessed exposure at an individual level, in two studies (one using personal and one stationary measurements) exposure was expressed at group level, while for one study it was unclear. In all eight studies, current exposure (prevalence) was assessed. Measurements between the years 1980 and 2014 were identified. Three studies included full-shift measurement (above 4 hours), and for the remaining five studies the sampling duration was unclear. Four studies presented a mean exposure level by AM (range 0.6–7.0 mg/m^3), one study by GM (0.6 mg/m^3), and three studies by other methods, e.g., range. For seven studies a prevalence estimate was available, ranging from 0.02 to 1.00.

Table 7
Study and measurement numbers by industrial sector, for prevalence and level of occupational exposure to coal dust.

Industrial sector	Prevalence				Level			
	Number of entries and studies	Number of countries	Number of regions	Number of measurements	Number of entries and studies	Number of countries	Number of regions	Number of measurements
Mining (coal and lignite)	6 entries from 6 studies	5	4	3309	5 entries from 3 studies	3	3	100,092
Electricity, gas and air supply	1 entry from 1 study	1	1	203	1 entry from 1 study	1	1	4

Table 8
Risk of bias in included studies, Prevalence and level of occupational exposure to silica by industrial sector Construction: Construction of buildings (41), Civil engineering (42), Specialized construction activities (43).

Cohort	Azari 2009	Bakke 2001	Bakke 2014	Galea 2016	Guenel 1989	Hammond 2016	Huizer 2010	Khoza 2012	Linch 2002	Nij 2003	Normohammadi 2016	Radnoff 2014	Rappaport 2003	Scarselli 2014	Tavakol 2017	Ulvestad 2000	Ulvestad 2001a	van Deurssen 2014	Woskie 2002	Yassin 2005
Meta-analysis	Prev, Level	Prev, Level	Prev, Level	Level	Prev	Prev, Level	Prev	Prev, Level	Prev	Prev, Level	Prev, Level	Prev, Level	Prev, Level	Prev, Level	Prev, Level	Prev, Level	Prev, Level	Prev, Level	Prev	Level
Industrial sector (ISIC 4)	41; 42	42; 43	42	42	42	42; 43	43	41	41	41	43	41; 42; 43	41; 43	41	41	41; 42	42; 43	41; 43	43	42
Bias in selection of participants into the study	H	PL	PL	PH	PH	PH	PH	H	H	PH	PL	PH	PH	PH	PL	PL	L	PL	PL	PH
Bias due to lack of blinding of study personnel	PL	PL	PL	PL	L	PL	PH	PH	PL	PH	PL	PL	PL	PL	PL	PL	PL	PL	PL	PL
Bias due to exposure misclassification	L	L	PH	PL	PL	L	PL	L	L	L	L	PH	L	PH	L	PL	PL	L	PH	PH
Bias due to incomplete exposure data	PL	PL	PL	PH	PH	PL	PH	PL	PL	PL	PL	PL	PH	NR	PL	PH	PL	PL	PL	L
Bias due to selective reporting of exposures	PL	L	L	PH	PL	PL	L	H	PL	PL	PL	L	PL	NR	NR	L	L	L	PL	L
Bias due to conflicts of interest	PL	PL	PH	PL	L	L	PH	PL	L	PL	L	PL	L	PH	PL	PH	PH	PL	L	PL
Bias due to differences in numerator and denominator	PH	L	L	PH	L	PH	PH	PH	PH	PL	PH	PL	PH	NR	L	NR	L	L	L	L
Other bias	L	PL	L	L	L	L	L	L	L	L	PH	L	L	L	PH	NR	L	L	L	PH

Legend

L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

4.3. Characteristics of studies awaiting classification

We did not identify any studies that are awaiting classification.

4.4. Risk of bias within studies

The risk of bias tables for each study with a rationale for the rating by RoB-SPEO risk of bias domain (Pega et al. 2020) are presented in Appendices 4-6 in the Supplementary data.

4.4.1. Occupational exposure to silica

Tables 8-13 present an overview of risk of bias in included studies by industrial sector, where ISIC-4 codes at the level of 2-digits were merged for Construction, Manufacture and Mining.

Table 9
Risk of bias in included studies, Prevalence and level of occupational exposure to silica by industrial sector Manufacturing: Manufacture of chemicals and chemical products (20), Manufacture of other non-metallic mineral product (23), Manufacture of basic metals (24), Manufacture of furniture (31), Other manufacturing (32).

Cohort	Andersson 2009	Azari 2009	Carneiro 2017	Chen 2007	Dion 2005	Chen 2012	Estellita 2010	Foreland 2008	Guenel 1989	Healy 2014	Koo 2000	Khoza 2012	Love 1999	Omidianidost 2015	Oudyk 1995	Radnoff 2014	Rees 1992	Rokni 2016	Saiyed 1995	Sayler 2018	Scarselli 2014	Siltanen 1976	Wang 2015	Yassin 2005	Zarei 2017	Zhuang 2001
Meta-analysis	Prev, Level	Prev, Level	Prev, Level	Prev	Prev	Prev, Level	Prev	Prev, Level	Prev	Prev	Prev	Prev, Level	Prev	Prev	Prev, Level	Prev, Level	Prev	Prev, Level	Prev	Prev, Level	Prev, Level	Prev	Prev	Level	Prev, Level	Prev, Level
Industrial sector (ISIC 4)	24	23; 24; 32	23	23	20	23	23	23	23; 42	23	24	23; 24; 32	23	24	24	23; 24; 32	23	23; 24; 32	32	23	23; 24; 31	24	23	24	24	23
Bias in selection of participants into the study	PL	H	PH	PH	PH	L	H	PH	PH	PL	H	H	L	PH	PL	PH	PL	L	PL	L	PH	PL	PL	PH	PL	H
Bias due to lack of blinding of study personnel	PH	PL	PL	PL	PL	PL	PL	PL	L	L	PH	PH	L	PL	L	PL	PL	PL	PL	NR	PL	PL	PL	PL	PL	PL
Bias due to exposure misclassification	PH	L	L	L	L	L	PH	L	PL	L	L	L	PL	H	H	PH	PL	L	PH	L	PH	L	PL	PH	L	PL
Bias due to incomplete exposure data	PH	PL	PL	PH	PL	PL	PL	PL	PH	PL	PH	PL	PL	PL	PL	PL	PL	L	H	L	NR	L	PL	L	L	PL
Bias due to selective reporting of exposures	PL	PL	PL	PL	PL	L	H	PL	PL	PL	PL	H	PL	L	L	L	PL	L	PL	L	NR	PH	PL	L	PL	PL
Bias due to conflicts of interest	PH	PL	PL	PL	PH	PL	PL	PL	L	PL	PL	PL	PH	PL	L	PL	L	L	PH	L	PH	PH	PL	PL	L	PL
Bias due to differences in numerator and denominator	L	PH	L	NR	L	L	L	NR	L	L	PH	PH	L	L	L	PL	PH	L	PL	NR	NR	L	PL	L	L	PH
Other bias	L	L	L	L	L	L	L	L	L	L	L	L	L	PL	L	L	L	L	L	NR	L	PL	NR	PH	PL	L

Legend

L Low PL Probably low PH Probably high H High NR Not reported/not applicable

4.4.1.1. Construction

4.4.1.1.1. Prevalence. Across the 18 included studies (Table 8), risk of bias was high or probably high for ten studies for bias in selection of participants into the study, three studies for bias due to lack of blinding of study personnel, four studies for bias due to exposure misclassification, four studies for bias due to incomplete exposure data, one study for bias due to selective reporting of exposures, five studies for bias due to conflicts of interest, seven studies for bias due to differences in numerator and denominator, and two studies for other bias.

4.4.1.1.2. Level. Across the 16 included studies (Table 8), risk of bias was high or probably high for nine studies for bias in selection of participants into the study, two studies for bias due to lack of blinding of study personnel, four studies for bias due to exposure misclassification, three studies for bias due to incomplete exposure data, two studies for bias due to selective reporting of exposures, four studies for bias due to conflicts of interest, six studies for bias due to differences in numerator and denominator, and three studies for other bias.

4.4.1.2. Manufacturing

4.4.1.2.1. Prevalence. Across the 25 included studies (Table 9), risk of bias was high or probably high for 13 studies for bias in selection of participants into the study, three studies for bias due to lack of blinding of study personnel, seven studies for bias due to exposure misclassification, five studies for bias due to incomplete exposure data, three studies for bias due to selective reporting of exposures, six studies for bias due to conflicts of interest and five studies for bias due to differences in numerator and denominator.

4.4.1.2.2. Level. Across the 14 included studies (Table 9), risk of bias was high or probably high for eight studies for bias in selection of participants into the study, two studies for bias due to lack of blinding of study personnel, five studies for bias due to exposure misclassification, one study for bias due to incomplete exposure data, one study for bias due to selective reporting of exposures, two studies for bias due to conflicts of interest, three studies for bias due to differences in numerator and denominator, and one study for other bias.

4.4.1.3. Mining

4.4.1.3.1. Prevalence. Across the 21 included studies (Table 10), risk of bias was high or probably high for nine studies for bias in selection of participants into the study, one study for bias due to lack of blinding of study personnel, four studies for bias due to exposure misclassification, four studies for bias due to incomplete exposure data, one study for bias due to selective reporting of exposures, one study for bias due to conflicts of interest, six studies for bias due to differences in numerator and denominator, and two studies for other bias.

4.4.1.3.2. Level. Across the 17 included studies (Table 10), risk of bias was high or probably high for six studies for bias in selection of participants into the study, one study for bias due to lack of blinding of study personnel, five studies for bias due to exposure misclassification, three studies for bias due to incomplete exposure data, one study for bias due to selective reporting of exposures, one study for bias due to conflicts of interest, five studies for bias due to differences in numerator and denominator, and two studies for other bias.

4.4.1.4. Crop and animal production

4.4.1.4.1. Prevalence. Across the three included studies (Table 11), risk of bias was high or probably high for one study for bias in selection of participants into the study, one study for bias due to lack of blinding of study personnel, one study for bias due to selective reporting of exposures, and one study for bias due to differences in numerator and denominator.

4.4.1.4.2. Level. Across the two included studies (Table 11), risk of

Table 10
Risk of bias in included studies, Prevalence and level of occupational exposure to silica for industrial sector Mining: Mining of coal and lignite (05), Mining of metal ores (07), Other mining and quarrying (08).

Cohort	Azari 2009	Chen 2012	Churchyard 2004	Estellita 2010	Golbabaei 2004	Gottesfeld 2015	Green 2008	Hayumbu 2008	Kreiss 1996	Kullman 1995	Lee, 2014	Love 1997	Mamuya 2006	Pandey 2018	Peters 2017	Radnoff 2014	Rando 2001	Rokni 2016	Sanderson 2000	Verma 2014	WattsJr 2012	Weeks 2006	Yassin 2005	Yingratanasuk 2002	Zhuang 2001
Meta-analysis	Prev, Level	Prev, Level	Prev, Level	Prev	Prev	Prev, Level	Prev	Prev	Level	Prev, Level	Prev	Prev	Prev, Level	Prev	Prev, Level	Prev, Level	Level	Prev, Level	Prev, Level	Prev, Level	Level	Prev, Level	Level	Prev	Prev, Level
Industrial sector (ISIC 4)	8	7	7	8	8	7	8	7	7	8	8	8	8	5	7	8	8	8	8	7	7,8	7	8	8	7
Bias in selection of participants into the study	H	L	PL	H	PH	PH	PH	PL	PH	PL	H	PL	PL	PH	L	PH	PL	L	PL	L	L	L	PH	PL	H
Bias due to lack of blinding of study personnel	PL	PL	L	PL	PL	PL	PL	PL	PL	L	L	PH	PL	L	PL	PL	PH	PL	PL	PL	L	L	PL	PL	PL
Bias due to exposure misclassification	L	L	L	PH	L	L	PL	PL	PH	L	H	L	PL	L	PL	PH	PH	L	PH	L	L	L	PH	PL	PL
Bias due to incomplete exposure data	PL	PL	PH	PL	PH	PL	PL	PL	PH	PL	L	PH	PH	L	PL	PL	L	L	PL	L	L	L	L	L	PL
Bias due to selective reporting of exposures	PL	L	PL	H	PL	PL	PL	PL	PH	PL	PL	PL	PL	PL	PL	L	L	L	PL	L	L	L	L	PL	PL
Bias due to conflicts of interest	PL	PL	PL	PL	NR	PL	PL	PL	PH	PL	PL	PH	L	PL	PL	PL	L	L	PL	PL	L	PL	PL	PL	PL
Bias due to differences in numerator and denominator	PH	L	L	L	NR	PH	PH	PL	L	PL	L	PL	PH	L	PL	PL	L	L	PH	L	L	L	L	PL	PH
Other bias	L	L	L	L	L	L	PH	L	L	L	L	L	L	L	L	L	NR	L	L	PH	L	L	PH	L	L

Legend

L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

bias was high or probably high for one study for bias in selection of participants into the study, one study for bias due to selective reporting of exposures, and one study for bias due to differences in numerator and denominator.

4.4.1.5. Electricity, gas, steam and air conditioning supply

4.4.1.5.1. Prevalence. Across the two included studies (Table 12), risk of bias was high or probably high for two studies for bias in selection of participants into the study and one study for bias due to exposure misclassification.

4.4.1.5.2. Level. For the one study in the body of evidence (Table 12), risk of bias was high or probably high for bias in selection of participants into the study and for bias due to exposure misclassification.

4.4.1.6. Professional, scientific and technical activities

4.4.1.6.1. Prevalence. For the one study in the body of evidence (Table 13), risk of bias was high or probably high for bias in selection of participants into the study and for bias due to differences in numerator and denominator.

4.4.1.6.2. Level. Across the two included studies (Table 13), risk of bias was high or probably high for two studies for bias in selection of participants into the study, one study for bias due to exposure misclassification and two studies for bias due to differences in numerator and denominator.

4.4.2. Occupational exposure to asbestos

Tables 14-18 present an overview of risk of bias in included studies by industrial sector, where ISIC-4 2-digit codes were merged for Construction (as here defined; not as per ISIC) and Manufacture (as here defined).

4.4.2.1. Construction

4.4.2.1.1. Prevalence. Across the six included studies (Table 14), risk of bias was high or probably high for one study for bias in selection of participants into the study, two studies for bias due to exposure misclassification, one studies for bias due to incomplete exposure data, one study for selective reporting of exposures, and one study for bias due to differences in numerator and denominator.

4.4.2.1.2. Level. Across the six included studies (Table 14), risk of bias was high or probably high for two studies for bias in selection of participants into the study, one study for bias due to exposure misclassification, and one study for bias due to incomplete exposure data.

4.4.2.2. Manufacturing

4.4.2.2.1. Prevalence. Across the seven included studies (Table 15), risk of bias was high or probably high for six studies for bias in selection of participants into the study, one study for bias due to exposure misclassification, one study for bias due to incomplete exposure data, two studies for bias due to selective reporting of exposures, three studies for bias due to differences in numerator and denominator, and two studies due to other bias.

4.4.2.2.2. Level. Across the five included studies (Table 15), risk of bias was high or probably high for five studies for bias in selection of participants into the study, one study for bias due to exposure misclassification, one study for bias due to incomplete exposure data, one study for bias due to selective reporting of exposures, and one study for bias due to differences in numerator and denominator.

4.4.2.3. Other mining and quarrying

4.4.2.3.1. Prevalence. For the one study in the body of evidence (Table 16), risk of bias was high or probably high for bias in selection of

Table 11
Risk of bias in included studies, Prevalence and level of occupational exposure to silica for industrial sector Crop and animal production (01).

Cohort	Archer 2003	Nieuwenhuijsen 1999	Swanepoel 2011
Meta-analysis	Prev, Level	Prev	Prev, Level
Industrial sector (ISIC 4)	1	1	1
Bias in selection of participants into the study	H	PL	PL
Bias due to lack of blinding of study personnel	L	PH	PL
Bias due to exposure misclassification	L	L	PL
Bias due to incomplete exposure data	L	PL	PL
Bias due to selective reporting of exposures	H	PL	PL
Bias due to conflicts of interest	L	L	PL
Bias due to differences in numerator and denominator	L	PL	PH
Other bias	L	L	L

Legend

L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

participants into the study, bias due to lack of blinding of study personnel, bias due to incomplete exposure data, bias due to selective reporting of exposures, and bias due to differences in numerator and denominator.

4.4.2.3.2. Level. The body of evidence for levels comprised the same study as the body of evidence for prevalence for occupational exposure to asbestos in Other mining and quarrying.

4.4.2.4. Electricity, gas, steam and air conditioning supply

4.4.2.4.1. Prevalence. Across the two included studies (Table 17), risk of bias was high or probably high for one study for bias in selection of participants into the study, one study for bias due to incomplete exposure data, and one study for bias due to differences in numerator and denominator.

4.4.2.4.2. Level. For the one study in the body of evidence (Table 17), risk of bias was high or probably high for bias in selection of participants into the study, bias due to incomplete exposure data, and bias due to differences in numerator and denominator.

4.4.2.5. Water supply, sewerage, waste management and remediation

4.4.2.5.1. Prevalence. No included studies considered prevalence of occupational exposure to asbestos in Water supply, sewerage, waste management and remediation.

4.4.2.5.2. Level. For the one study in the body of evidence (Table 18), risk of bias was rated low across all domains.

4.4.3. Prevalence and level of occupational exposure to coal dust by industrial sector

Tables 19-20 present an overview of risk of bias in included studies by industrial sector.

4.4.3.1. Mining of coal and lignite

4.4.3.1.1. Prevalence. Across the six included studies (Table 19), risk of bias was high or probably high for four studies for bias in selection of participants into the study, one study for bias due to lack of blinding of study personnel, two studies for bias due to incomplete exposure data, one study for bias due to selective reporting of exposures, two studies for bias due to conflicts of interest, and two studies for bias due to differences in numerator and denominator.

4.4.3.1.2. Level. Across the three included studies (Table 19), risk of bias was high or probably high for three studies for bias in selection of participants into the study, one study due to exposure misclassification, one study for bias due to incomplete exposure data, two studies for bias due to selective reporting of exposures, and one study for bias due to differences in numerator and denominator.

4.4.3.2. Electricity, gas, steam and air conditioning supply

4.4.3.2.1. Prevalence. For the one study in the body of evidence

Table 12
Risk of bias in included studies, Prevalence and level of occupational exposure to silica for industrial sector Electricity, gas, steam and air conditioning supply (35).

Cohort	Hicks 2006	Radnoff 2014a-2014b
Meta-analysis	Prev	Prev, Level
Industrial sector (ISIC 4)	35	35
Bias in selection of participants into the study	PH	PH
Bias due to lack of blinding of study personnel	L	PL
Bias due to exposure misclassification	L	PH
Bias due to incomplete exposure data	PL	PL
Bias due to selective reporting of exposures	PL	L
Bias due to conflicts of interest	L	PL
Bias due to differences in numerator and denominator	PL	PL
Other bias	L	L

Legend

L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

(Table 20), risk of bias was rated low across all domains.

4.4.3.2.2. Level. The body of evidence for level of exposure comprised the same study as the body of evidence for prevalence for occupational exposure to coal dust in Electricity, gas, steam and air conditioning supply.

4.4.4. Results from studies excluded from the meta-analysis

Tables on results from studies excluded from the *meta*-analyses on prevalences and levels for silica, asbestos and coal dust, respectively, as well as the reasons for their exclusion from the *meta*-analyses are available in Appendix 7 of the Supplementary data. The results are briefly described below by type of exposure.

4.4.4.1. Occupational exposure to silica. Nine out of 65 silica studies were not included in the *meta*-analyses for prevalence. For seven studies, no information on the prevalence was available, and for the two remaining studies, the prevalence ranges between 5% and up to “below 100%”.

Twenty-five out of 65 silica studies were not included in the *meta*-analyses for level of exposure. Not included studies did not present an eligible summary measure for *meta*-analysis and had a large variability in exposure levels ranging from LOD to 47 mg/m^3. Taken together, the excluded studies did not systematically present lower or higher levels compared to the *meta*-analysed result.

4.4.4.2. Occupational exposure to asbestos. Two out of 18 asbestos studies were not included in the *meta*-analysis for prevalence. In these two studies no information on the actual prevalence was available.

Six out of 18 asbestos studies were not included in the *meta*-analyses for level of exposure. Not included studies did not present an eligible summary measure for *meta*-analysis and had a large variability in exposure levels ranging from LOD to 16 f/ml. The excluded studies tended to present higher exposure levels compared to the *meta*-analyzed results.

4.4.4.3. Occupational exposure to coal dust. One out of eight coal dust studies was not included in the *meta*-analysis for prevalence. For this study no information on prevalence was available.

Four out of eight coal dust studies were not included in the *meta*-analyses for level of exposure. The studies that were not included did not present an eligible summary measure for *meta*-analysis and had a large variability in exposure levels ranging from 0.02 to 30 mg/m^3. Exposure levels tend to be higher compared to the *meta*-analyzed results.

4.5. Evidence synthesis

Measurements from each of the sectors were considered sufficiently clinically homogenous to be included in the same quantitative *meta*-analysis, where ISIC-4 2-digit coded were merged for construction, manufacture and mining. Clinical homogeneity is the lack of clinical heterogeneity, which can be defined as “differences in participant characteristics, [and] types or timing of outcome [or exposure]

Table 13
Risk of bias in included studies, Prevalence and level of occupational exposure to silica for industrial sector Professional, scientific and technical activities (71, 74).

Cohort	Grove 2014	Love 1997	Lu 2016	Mamuya 2006	Piacitelli 1990	Tripathy 2015	Wang 2015
Meta-analysis	Prev	Prev	Prev, Level	Prev, Level	Level	Prev	Prev
Industrial sector (ISIC 4)	5	5	5	5	5	5	5
Bias in selection of participants into the study	PH	PL	PH	PH	H	H	L
Bias due to lack of blinding of study personnel	L	PH	NR	PL	PL	PL	NR
Bias due to exposure misclassification	L	L	L	PL	PH	L	L
Bias due to incomplete exposure data	PL	PH	PL	PH	PL	PL	NR
Bias due to selective reporting of exposures	PL	PL	PH	PL	PH	PL	L
Bias due to conflicts of interest	PL	PH	L	L	L	H	NR
Bias due to differences in numerator and denominator	L	PL	PL	PH	PL	PH	NR
Other bias	L	L	L	L	L	L	NR

Legend

L Low PL Probably low PH Probably high H High NR Not reported/not applicable

measurements" (Chess and Gagnier 2016).

4.5.1. Occupational exposure to silica

4.5.1.1. Construction (ISIC 41–43)

4.5.1.1.1. Prevalence. The pooled prevalence estimate for Construction (ISIC 41–43, 17 studies, 2479 measurements, eight countries), was 0.89 (95% CI 0.84 to 0.93), with a moderate statistical heterogeneity (I^2 91%) (Fig. 2).

4.5.1.1.2. Level. The pooled level estimate for Construction (ISIC 41–43, 16 studies, 2352 measurements, seven countries), was 0.06 mg/m^3 (95% CI 0.05 to 0.06), with a high statistical heterogeneity (I^2 100%) (Fig. 3).

4.5.1.2. Manufacturing (ISIC 20, 23–25, 27, 31–32)

4.5.1.2.1. Prevalence. The pooled prevalence estimate for Manufacturing (ISIC 20, 23–25, 27, 31–32, 24 studies, 40,073 measurements, 14 countries), was 0.85 (95% CI 0.78 to 0.91), with a high statistical heterogeneity (I^2 100%) (Fig. 4).

4.5.1.2.2. Level. The pooled level estimate for Manufacturing (ISIC 20, 23–25, 27, 31–32, 13 studies, 7733 measurements, nine countries), was 0.10 mg/m^3 (95% CI 0.09 to 0.11), with a high statistical heterogeneity (I^2 100%) (Fig. 5).

4.5.1.3. Mining (ISIC 05, 07, 08)

4.5.1.3.1. Prevalence. The pooled prevalence estimate for Mining (ISIC 05, 07, 08, 20 studies, 222,276 measurements, 13 countries), was 0.75 (95% CI 0.68 to 0.82), with a high statistical heterogeneity (I^2 100%) (Fig. 6).

4.5.1.3.2. Level. The pooled level estimate for Mining (ISIC 05, 07, 08, 17 studies, 2,429,043 measurements, seven countries), was 0.04 mg/m^3 (95% CI 0.03 to 0.05), with a high statistical heterogeneity (I^2 100 %) (Fig. 7).

4.5.1.4. Crop and animal production, hunting and related service activities (ISIC 01)

4.5.1.4.1. Prevalence. The pooled prevalence estimate for Crop and animal production, hunting and related service activities (ISIC 01, three studies, 479 measurements, two countries), was 0.67 (95% CI 0.48 to 0.84), with a moderate statistical heterogeneity (I^2 93%) (Fig. 8).

4.5.1.4.2. Level. The pooled level estimate for Crop and animal production, hunting and related service activities (ISIC 01, two studies, 335 measurements, two countries), was 0.13 mg/m^3 (95% CI −0.09 to 0.35), with a moderate statistical heterogeneity (I^2 89 %) (Fig. 9).

4.5.1.5. Electricity, gas, steam and air conditioning supply (ISIC 35)

4.5.1.5.1. Prevalence. The pooled prevalence estimate for Electricity, gas, steam and air conditioning supply (ISIC 35, two studies, 136 measurements, two countries), was 0.69 (95% CI 0.51 to 0.84), with a moderate statistical heterogeneity (I^2 66%) (Fig. 10).

4.5.1.5.2. Level. The level estimate for Electricity, gas, steam and air conditioning supply (ISIC 35) came from one study (28 measurements, one country). The estimate produced, once entered into RevMan, was 0.02 mg/m^3 (95% CI −0.01 to 0.06).

Table 14
Risk of bias in included studies, Prevalence and level of occupational exposure to asbestos for industrial sector Construction: Construction of buildings (41), Specialized construction activities (43), Wholesale, retail trade, repair of vehicles and motorbikes (45).

Cohort	Kakooei 2014	Kauffer 2007	Maino 1995	Massaro 2012	Perkins 2008	Scarselli 2016	Wilmoth 1994
Meta-analysis	Prev, Level	Level	Prev, Level	Prev, Level	Prev, Level	Prev, Level	Prev
Industrial sector (ISIC 4)	43	41, 43, 45	43	43	43	41, 43	43
Bias in selection of participants into the study	PL	PH	PH	PL	L	L	PL
Bias due to lack of blinding of study personnel	PL	PL	PL	PL	L	L	PL
Bias due to exposure misclassification	PL	PL	PH	L	L	L	PH
Bias due to incomplete exposure data	L	PL	PH	L	PL	L	L
Bias due to selective reporting of exposures	PL	PL	PL	PL	L	L	PH
Bias due to conflicts of interest	PL	PL	PL	PL	L	L	PL
Bias due to differences in numerator and denominator	PL	PL	PL	PL	L	L	PH
Other bias	L	L	L	L	L	L	L

Legend
L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

4.5.1.6. Professional, scientific and technical activities (ISIC 71,74)

4.5.1.6.1. Prevalence. The prevalence estimate for Professional, scientific and technical activities (ISIC 71,74) came from one study (41 measurements, 1 country). The estimate produced, once entered into MetaXL, was 0.99 (95% CI 0.96 to 1.00).

4.5.1.6.2. Level. The pooled level estimate for Professional, scientific and technical activities (ISIC 71, 74, two studies, 87 measurements, two countries), was 0.01 mg/m^3 (95% CI −0.00 to 0.02), with a moderate statistical heterogeneity (I^2 86 %) (Fig. 11).

4.5.2. Occupational exposure to asbestos

4.5.2.1. Construction (ISIC 41, 43, 45)

4.5.2.1.1. Prevalence. The pooled prevalence estimate for Construction (ISIC 41, 43, 45, six studies, 16,580 measurements, three countries), was 0.77 (95% CI 0.65 to 0.87), with a high statistical heterogeneity (I^2 99%) (Fig. 12).

4.5.2.1.2. Level. The pooled level estimate for Construction (ISIC 41, 43, 45, six studies, 12,240 measurements, four countries), was 0.02 f/cm^3 (95% CI 0.01 to 0.02), with a high statistical heterogeneity (I^2 100 %) (Fig. 13).

4.5.2.2. Manufacturing (ISIC 13, 23, 24, 29, 30)

4.5.2.2.1. Prevalence. The pooled prevalence estimate for Manufacturing (ISIC 13, 23, 24, 29, 30, seven studies, 1225 measurements, five countries), was 0.99 (95% CI 0.96 to 1.00), with a moderate statistical heterogeneity (I^2 75%) (Fig. 14).

The pooled level estimate for Manufacturing (ISIC 13, 23, 24, 29, 30, five studies, 1432 measurements, five countries), was 0.16 f/cm^3 (95% CI 0.10 to 0.21), with a high statistical heterogeneity (I^2 97 %) (Fig. 15).

4.5.2.3. Other mining and quarrying (ISIC 08)

4.5.2.3.1. Prevalence. The pooled prevalence estimate for Other mining and quarrying (ISIC 08) came from one study (89 measurements, one country). The estimate produced, once entered into MetaXL, was 0.85 (95% CI 0.77 to 0.91).

4.5.2.3.2. Level. The pooled level estimate for Other mining and quarrying (ISIC 08) came from one study (89 measurements, one country). The estimate produced, once entered into RevMan, was 0.01 f/cm^3 (95% CI 0.01 to 0.02).

4.5.2.4. Electricity, gas, steam and air conditioning supply (ISIC 35)

4.5.2.4.1. Prevalence. The pooled prevalence estimate for Electricity, gas, steam and air conditioning supply (ISIC 35, two studies, 108 measurements, two countries), was 0.64 (95% CI 0.00 to 1.00), with a high statistical heterogeneity (I^2 99%) (Fig. 16).

4.5.2.4.2. Level. The level estimate for Electricity, gas, steam and air conditioning supply (ISIC 35) came from one study (46 measurements, one country). The estimate produced, once entered into RevMan, was 0.40 f/cm^3 (95% CI 0.21 to 0.58).

4.5.2.5. Water supply; sewerage, waste management and remediation (ISIC 37)

4.5.2.5.1. Prevalence. There were no included studies that considered prevalence of occupational exposure to asbestos in the industrial sector of Water supply; sewerage, waste management and remediation (ISIC 37).

4.5.2.5.2. Level. The level estimate for Water supply; sewerage, waste management and remediation (ISIC 37) came from one study (4507 measurements, one country). The estimate produced, once entered into RevMan, was 0.00 f/cm^3 (95% CI 0.00 to 0.00).

Table 15
Risk of bias in included studies, Prevalence and level of occupational exposure to asbestos for industrial sector Manufacturing: Manufacture of textiles (13), Manufacture of other non-metallic mineral product (23), Manufacture of basic metals (24), Manufacture of motor vehicles, trailers and semi-trailers (29), Manufacture of other transport equipment (30).

Cohort	Ahmad Ansari 2007	Borton 2012	Kakooei 2007	Kauffer 2007	Marioryad 2011	Panahi 2011	Phanprasit 2009	Wang 2012
Meta-analysis	Prev, Level	Prev	Prev	Level	Prev, Level	Prev, Level	Prev, Level	Prev
Industrial sector (ISIC 4)	23	23	30	13, 23 24, 29	23	23	23	23
Bias in selection of participants into the study	H	PH	H	PH	PH	PH	PH	L
Bias due to lack of blinding of study personnel	PL	PL	PL	PL	PL	PL	PL	PL
Bias due to exposure misclassification	L	PL	L	PL	L	PH	L	PL
Bias due to incomplete exposure data	PL	PL	PL	PL	PL	PH	L	L
Bias due to selective reporting of exposures	PL	PL	PH	PL	PL	H	PL	L
Bias due to conflicts of interest	PL	PL	PL	PL	L	L	PL	PL
Bias due to differences in numerator and denominator	L	PH	PH	PL	PH	L	NR	PL
Other bias	L	L	PH	L	L	L	L	PH

Legend
L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

4.5.3. Occupational exposure to coal dust

4.5.3.1. Mining of coal and lignite (ISIC 05)

4.5.3.1.1. Prevalence. The pooled prevalence estimate for Mining of coal and lignite (ISIC 05, six studies, 3309 measurements, five countries), was 1.00 (95% CI 1.00 to 1.00), with a low statistical heterogeneity (I^2 16%) (Fig. 17).

4.5.3.1.2. Level. The pooled level estimate for Mining of coal and lignite (ISIC 05, three studies, 100,092 measurements, three countries), was 0.77 mg/m^3 (95% CI 0.68 to 0.86), with a high statistical heterogeneity (I^2 100%) (Fig. 18).

4.5.3.2. Electricity, gas, steam and air conditioning supply (ISIC 35)

4.5.3.2.1. Prevalence. The prevalence estimate for Electricity, gas, steam and air conditioning supply (ISIC 35) came from one study (203 measurements, one country). The estimate produced, once entered into MetaXL, was 0.02 (95% CI 0.00 to 0.04).

4.5.3.2.2. Level. The level estimate for Electricity, gas, steam and air conditioning supply (ISIC 35) came from one study (four measurements, one country). The estimate produced, once entered into RevMan, was 0.60 mg/m^3 (95% CI −6.95 to 8.14).

4.6. Additional analyses

4.6.1. Subgroup analysis, by WHO region

Forest plots for subgroup analyses by WHO region can be found in Appendices 8–10 of the Supplementary data for exposures that have data for two or more WHO regions.

4.6.1.1. Occupational exposure to silica. Table 21 presents the subgroup analyses for results by WHO region for prevalence and level of occupational exposure to silica for each industrial sector. For industrial sectors with more entries (Construction, Manufacturing and Mining) a large statistical heterogeneity within and between WHO regions was indicated suggesting that the prevalences and levels may differ substantially by WHO region for these industrial sectors. For the remaining sectors the number of entries was too limited to draw any conclusion.

4.6.1.2. Occupational exposure to asbestos. Table 22 presents the subgroup analyses for results by WHO region for prevalence and level of occupational exposure to asbestos for each industrial sector.

For industrial sectors with more entries (Construction and Manufacturing) a large statistical heterogeneity within and between WHO regions was indicated suggesting that the prevalences and levels may differ substantially by WHO region for these industrial sectors. For the remaining sectors the number of entries was limited. For the remaining sectors the number of entries was too limited to draw any conclusion.

4.6.1.3. Occupational exposure to coal dust. Table 23 presents the subgroup analyses for results by WHO region for prevalence and level of occupational exposure to coal dust for each industrial sector.

For the single industrial sector with more entries (Mining of coal and lignite) a low statistical heterogeneity and a very similar prevalence (99–100%) within and between WHO regions was evident. For levels, a large statistical heterogeneity was indicated suggesting that the levels may differ substantially by WHO region. For the remaining sectors the

Table 16
Risk of bias in included studies, Prevalence and level of occupational exposure to asbestos for industrial sector Other mining and quarrying (08).

Cohort	Cattaneo 2012
Meta-analysis	Prev, Level
Industrial sector (ISIC 4)	8
Bias in selection of participants into the study	PH
Bias due to lack of blinding of study personnel	PH
Bias due to exposure misclassification	PL
Bias due to incomplete exposure data	PH
Bias due to selective reporting of exposures	PH
Bias due to conflicts of interest	PL
Bias due to differences in numerator and denominator	PH
Other bias	L

Legend
L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

Table 17
Risk of bias in included studies, Prevalence and level of occupational exposure to asbestos for industrial sector Electricity, gas, steam and air conditioning supply (35).

Cohort	Bird 2004	Damiran 2015
Meta-analysis	Prev	Prev, Level
Industrial sector (ISIC 4)	35	35
Bias in selection of participants into the study	L	H
Bias due to lack of blinding of study personnel	L	PL
Bias due to exposure misclassification	L	L
Bias due to incomplete exposure data	L	PH
Bias due to selective reporting of exposures	PL	PL
Bias due to conflicts of interest	PL	PL
Bias due to differences in numerator and denominator	L	PH
Other bias	L	L

Legend
L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

Table 18
Risk of bias in included studies, Prevalence and level of occupational exposure to asbestos for industrial sector Water supply, sewerage, waste management and remediation (37).

Cohort	Scarselli 2016
Meta-analysis	Level
Industrial sector (ISIC 4)	37
Bias in selection of participants into the study	L
Bias due to lack of blinding of study personnel	L
Bias due to exposure misclassification	L
Bias due to incomplete exposure data	L
Bias due to selective reporting of exposures	L
Bias due to conflicts of interest	L
Bias due to differences in numerator and denominator	L
Other bias	L

Legend

L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

Table 19
Risk of bias in included studies, Prevalence and level of occupational exposure to coal dust for industrial sector Mining of coal and lignite (05).

Cohort	Grove 2014	Love 1997	Lu 2016	Mamuya 2006a-b	Piacitelli 1990	Tripathy 2015	Wang 2015
Meta-analysis	Prev	Prev	Prev, Level	Prev, Level	Level	Prev	Prev
Industrial sector (ISIC 4)	5	5	5	5	5	5	5
Bias in selection of participants into the study	PH	PL	PH	PH	H	H	L
Bias due to lack of blinding of study personnel	L	PH	NR	PL	PL	PL	NR
Bias due to exposure misclassification	L	L	L	PL	PH	L	L
Bias due to incomplete exposure data	PL	PH	PL	PH	PL	PL	NR
Bias due to selective reporting of exposures	PL	PL	PH	PL	PH	PL	L
Bias due to conflicts of interest	PL	PH	L	L	L	H	NR
Bias due to differences in numerator and denominator	L	PL	PL	PH	PL	PH	NR
Other bias	L	L	L	L	L	L	NR

Legend

L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

Table 20
Risk of bias in included studies, Prevalence and level of occupational exposure to coal dust for industrial sector Electricity, gas, steam and air conditioning supply (35).

Cohort	Bird 2004
Meta-analysis	Prev, Level
Industrial sector (ISIC 4)	35
Bias in selection of participants into the study	L
Bias due to lack of blinding of study personnel	L
Bias due to exposure misclassification	L
Bias due to incomplete exposure data	L
Bias due to selective reporting of exposures	PL
Bias due to conflicts of interest	PL
Bias due to differences in numerator and denominator	L
Other bias	L

Legend

L Low; PL Probably low; PH Probably high; H High; NR Not reported/not applicable

number of entries was too limited to draw any conclusion.

4.6.2. Sensitivity analysis, by risk of bias due to selection of participants into studies

We carried out sensitivity analyses for each exposure to assess whether pooled estimates varied between studies considered at high/probably high risk of bias due to selection of participants into studies versus studies considered at low/probably low risk of bias due to selection of participants into studies. Forest plots are shown in Appendices 11–13 in the Supplementary data, for exposures whose bodies of evidence comprised studies with both high/probably high and low/probably low risk of bias due to selection of participants into studies.

4.6.2.1. Occupational exposure to silica. Table 24 presents the sensitivity analyses for results by risk of bias due to selection region for prevalence and level of occupational exposure to silica.

4.6.2.2. Occupational exposure to asbestos. Table 25 presents the sensitivity analyses for results by WHO region for prevalence and level of occupational exposure to asbestos for each industrial sector.

4.6.2.3. Occupational exposure to coal dust. Table 26 presents the sensitivity analyses for results by WHO region for prevalence and level of occupational exposure to coal dust for each industrial sector.

4.7. Quality of evidence

Using the QoE-SPEO approach (Pega et al. 2022b) for assessing quality of evidence of the entire body of evidence that WHO developed specifically for the WHO/ILO Joint Estimates, we judged the quality of evidence for each exposure, starting from a rating of high. Funnel plots, used in the assessment of publication bias for bodies of evidence comprising at least 10 studies, can be found in Appendix 14 of the Supplementary data (silica only, as no body of evidence related to asbestos or coal dust comprised 10 studies or more). Additionally, detailed information about the quality of evidence assessments can be found in the templates used for the assessment in Appendices 15–17.

4.7.1. Occupational exposure to silica

Table 27 displays the expected heterogeneity, number of downgrades and reasons for downgrading, and the final quality of evidence score for prevalence and level of occupational exposure to silica.

4.7.2. Occupational exposure to asbestos

Table 28 displays the expected heterogeneity, number of downgrades and reasons for downgrading, and the final quality of evidence score for prevalence and level of occupational exposure to asbestos.

4.7.3. Occupational exposure to coal dust

Table 29 displays the expected heterogeneity, number of downgrades and reasons for downgrading, and the final quality of evidence score for prevalence and level of occupational exposure to coal dust.

5. Discussion

5.1. Summary of evidence

5.1.1. Occupational exposure to silica

The summary of findings for prevalence and level of occupational exposure to silica in each industrial sector is shown in Table 30.

5.1.1.1. Construction. The pooled prevalence estimate was 0.89 (95% CI 0.84 to 0.93, I^2 91%, 17 studies, moderate quality of evidence) for occupational exposure to silica in Construction, and the pooled level estimate was 0.06 mg/m^3 (95% CI 0.05 to 0.06, I^2 100%, 16 studies, very low quality of evidence).

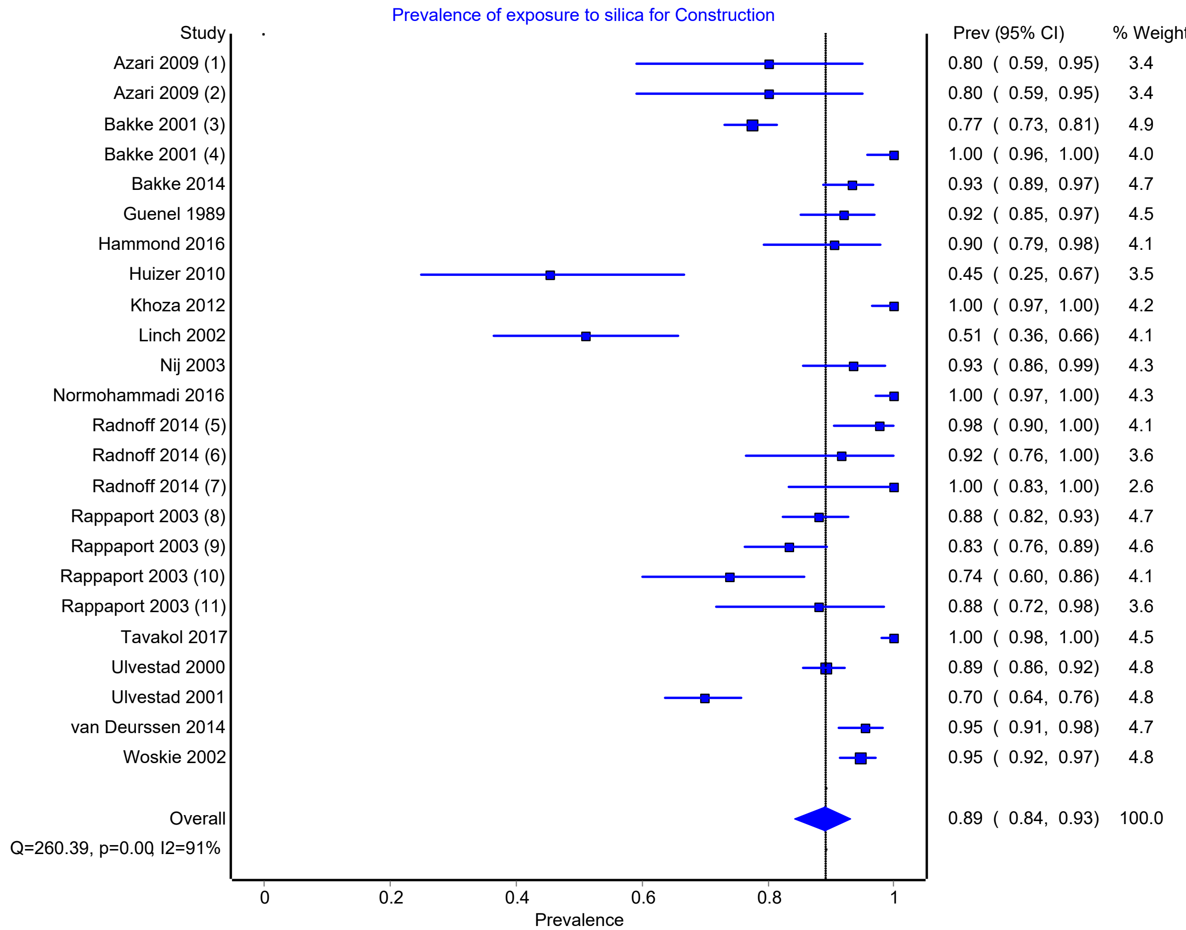


Fig. 2. Main *meta*-analysis, prevalence of occupational exposure to silica, Construction ISIC 41–43.

5.1.1.2. Manufacturing. The pooled prevalence estimate was 0.85 (95% CI 0.78 to 0.91, I^2 100%, 24 studies, moderate quality of evidence) for occupational exposure to silica in Manufacturing, and the pooled level estimate was 0.10 mg/m^3 (95% CI 0.09 to 0.11, I^2 100%, 14 studies, very low quality of evidence).

5.1.1.3. Mining. The pooled prevalence estimate was 0.75 (95% CI 0.68 to 0.82, I2 100%, 20 studies, moderate quality of evidence) for occupational exposure to silica in Mining, and the pooled level estimate was 0.04 mg/m^3 (95% CI 0.03 to 0.05, I2 100%, 17 studies, low quality of evidence).

5.1.1.4. Crop and animal production. The bodies of evidence for the pooled prevalence estimate and the pooled level estimate for Crop and animal production were judged to be of very low quality of evidence.

5.1.1.5. Electricity, gas, steam and air conditioning supply. The bodies of evidence for the pooled prevalence estimate and the pooled level estimate for Electricity, gas, steam and air conditioning supply were judged to be of very low quality of evidence.

5.1.1.6. Professional, scientific and technical activities. The bodies of evidence for the pooled prevalence estimate and the pooled level estimate for Professional, scientific and technical activities were judged to be of very low quality of evidence.

5.1.2. Occupational exposure to asbestos

Table 31 presents the summary of findings for prevalence and level of occupational exposure to asbestos by industrial sector.

5.1.2.1. Construction. The pooled prevalence estimate was 0.77 (95% CI 0.65 to 0.87, I^2 99%, six studies, low quality of evidence) for occupational exposure to asbestos in Construction. The body of evidence for the pooled level estimate for Construction was judged to be of very low quality of evidence.

5.1.2.2. Manufacturing. The bodies of evidence for the pooled prevalence estimate and the pooled level estimate for Manufacturing were judged to be of very low quality of evidence.

5.1.2.3. Mining (other mining and quarrying). The bodies of evidence for the pooled prevalence estimate and the pooled level estimate for Mining were judged to be of very low quality of evidence.

5.1.2.4. Electricity, gas, steam and air conditioning supply. The bodies of evidence for the pooled prevalence estimate and the pooled level estimate for Electricity, gas, steam and air conditioning supply were judged to be of very low quality of evidence.

5.1.2.5. Water supply, sewerage, waste management and remediation. The body of evidence for the pooled level estimate for Water supply, sewerage, waste management and remediation was judged to be of very low quality of evidence.

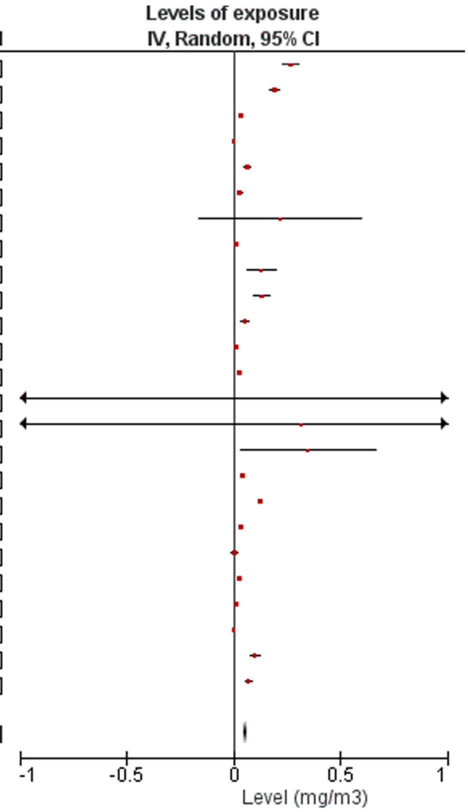
5.1.3. Occupational exposure to coal dust

Table 32 presents the summary of findings for prevalence and level of occupational exposure to silica by industrial sector are shown.

5.1.3.1. Mining (coal and lignite). The pooled prevalence estimate was

Study or Subgroup	Levels of exposure	SE	Weight	Levels of exposure IV, Random, 95% CI
Azari 2009 (1)	0.267	0.017797	3.0%	0.27 [0.23, 0.30]
Azari 2009 (2)	0.193	0.01084	4.2%	0.19 [0.17, 0.21]
Bakke 2001 (3)	0.035	0.003574	5.4%	0.04 [0.03, 0.04]
Bakke 2001 (4)	0.002	0.000211	5.6%	0.00 [0.00, 0.00]
Bakke 2014	0.063	0.006488	5.0%	0.06 [0.05, 0.08]
Galea 2016	0.03	0.004674	5.3%	0.03 [0.02, 0.04]
Hammond 2016	0.218	0.193343	0.1%	0.22 [-0.16, 0.60]
Khoza 2012	0.01	0.001706	5.5%	0.01 [0.01, 0.01]
Nij 2003	0.13	0.034944	1.3%	0.13 [0.06, 0.20]
Normohammadi 2016	0.132	0.018835	2.9%	0.13 [0.10, 0.17]
Radnoff 2014 (5)	0.055	0.009938	4.4%	0.06 [0.04, 0.07]
Radnoff 2014 (6)	0.013	0.002549	5.5%	0.01 [0.01, 0.02]
Radnoff 2014 (7)	0.027	0.005159	5.2%	0.03 [0.02, 0.04]
Rappaport 2003 (8)	1.28	1.175209	0.0%	1.28 [-1.02, 3.58]
Rappaport 2003 (9)	0.32	0.817014	0.0%	0.32 [-1.28, 1.92]
Rappaport 2003 (10)	0.35	0.16283	0.1%	0.35 [0.03, 0.67]
Scarselli 2014	0.045	0.0011	5.5%	0.04 [0.04, 0.05]
Tavakol 2017	0.129	0.00206	5.5%	0.13 [0.12, 0.13]
Ulvestad 2000 (11)	0.034	0.005437	5.2%	0.03 [0.02, 0.04]
Ulvestad 2000 (12)	0.003	0.006327	5.0%	0.00 [-0.01, 0.02]
Ulvestad 2001 (13)	0.026	0.002762	5.4%	0.03 [0.02, 0.03]
Ulvestad 2001 (14)	0.015	0.001769	5.5%	0.01 [0.01, 0.02]
Ulvestad 2001 (15)	0.002	0.00033	5.6%	0.00 [0.00, 0.00]
van Deurssen 2014	0.1	0.012304	4.0%	0.10 [0.08, 0.12]
Yassin 2005	0.07	0.006615	5.0%	0.07 [0.06, 0.08]
Total (95% CI)			**100.0%**	**0.06 [0.05, 0.06]**

Heterogeneity: Tau² = 0.00; Chi² = 6324.69, df = 24 (P < 0.00001); I² = 100%
Test for overall effect: Z = 12.04 (P < 0.00001)



Footnotes
(1) ISIC 42
(2) ISIC 41
(3) ISIC 42, tunnel construction
(4) ISIC 42, tunnel construction
(5) ISIC 41
(6) ISIC 42
(7) ISIC 43
(8) ISIC 43, construction, bricklayers
(9) ISIC 43, construction, painters
(10) ISIC 41
(11) ISIC 42, tunnel construction
(12) ISIC 42, tunnel construction, outdoor
(13) ISIC 42, construction, drilling
(14) ISIC 42, shotcretes
(15) ISIC 42, construction, outdoor

Fig. 3. Main *meta*-analysis, level of occupational exposure to silica, Construction ISIC 41–43.

1.00 (95% CI 1.00 to 1.00, I^2 16%, six studies, moderate quality of evidence) for occupational exposure to silica in Mining (coal and lignite), and the pooled level estimate was 0.77 mg/m^3 (95% CI 0.68 to 0.86, I^2 100%, three studies, low quality of evidence).

5.1.3.2. Electricity, gas, steam and air conditioning supply. The body of evidence for the pooled prevalence estimate for Electricity, gas, steam and air conditioning supply was judged to be of very low quality of evidence. The pooled level estimate was 0.60 mg/m3 (95% CI −6.95 to 8.14, one study, low quality of evidence).

5.2. Comparison with previous systematic reviews evidence

There has only been a prior scoping review on this topic, which only looked at occupational exposures to silica and asbestos among industrial workers in one country, namely Thailand (Kunpeuk et al. 2021). Similar to our systematic review, this scoping review found that most included studies reported the prevalences of occupational exposure to be 100% for both silica and asbestos, with two studies on occupational silica exposure reporting a lower prevalence (50% and 74%, respectively). The scoping review did not report a *meta*-analysis.

5.3. Strength and limitations of this review

Our systematic review included 65 silica studies (62 included in *meta*-analysis) covering all six WHO regions, 18 asbestos studies (17 included in *meta*-analysis) covering five WHO regions (Region of the Americas, South-East Asia Region, European Region, Eastern Mediterranean Region, and Western Pacific Region), and eight coal dust studies (all included in *meta*-analysis) covering four WHO regions (African Region, Region of the Americas, South-East Asia Region, and European Region). This systematic review examines the bodies of evidence for both prevalence and level of these three occupational exposures by industrial sector.

Globally, we aimed to include all silica, asbestos and coal dust measurements at workplaces performed since 1960. Even though we

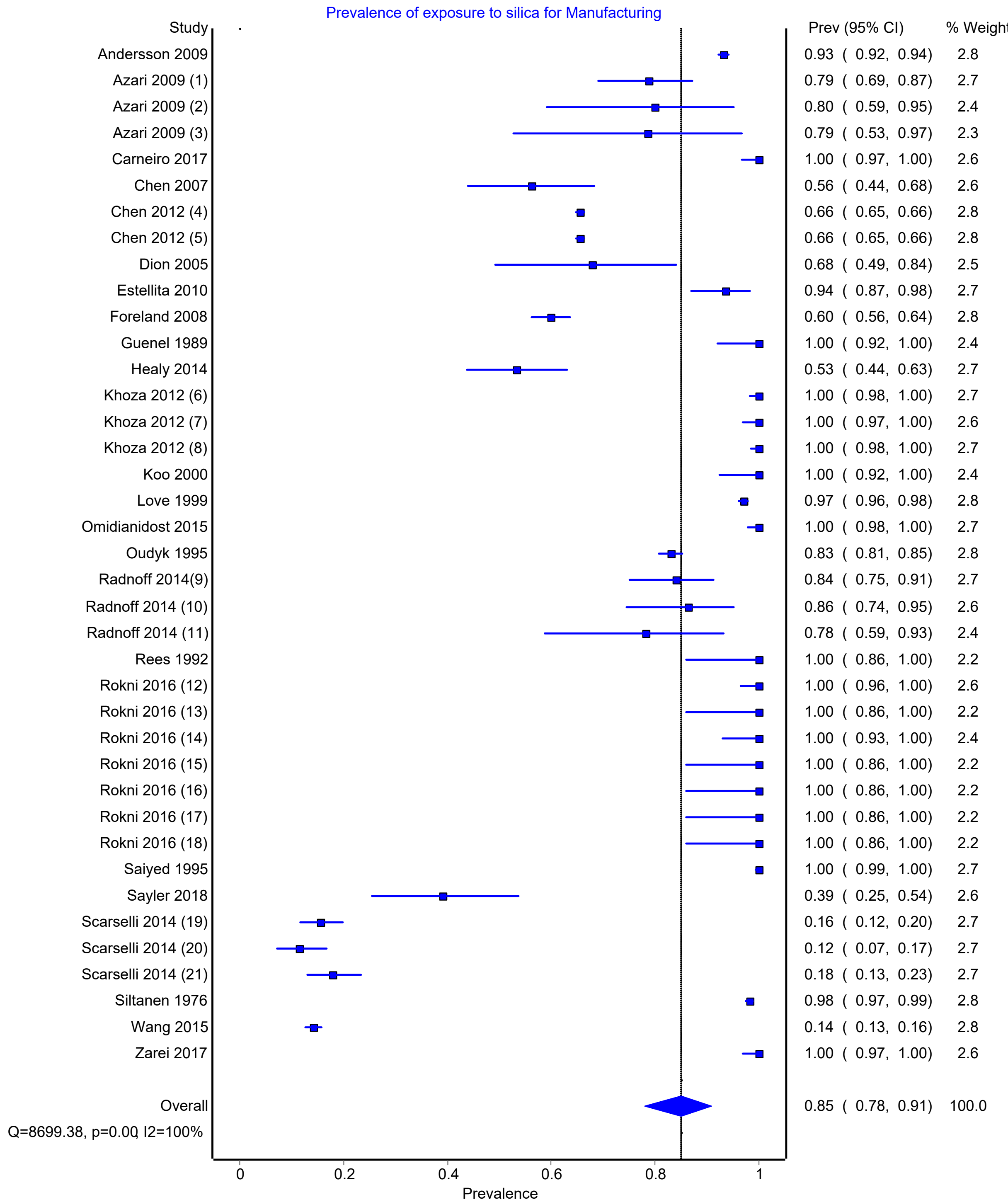


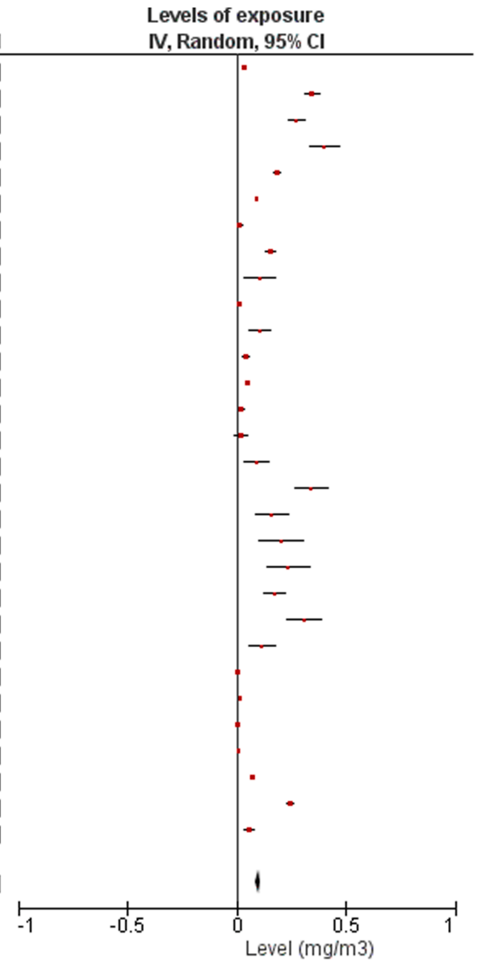
Fig. 4. Main *meta*-analysis, prevalence of occupational exposure to silica, Manufacturing ISIC 20, 23–25, 27, 31–32.

systematically searched for measurement data in both academic and grey literature, it is evident we did not succeed in including all measurements of relevance. One main reason is that the study records from included studies often did not report the data of interest (see for example Heederik and Attfield (2000); Schonfeld et al. (2017)), and we were only able to include additional measurements to a limited extent after data requests from the principal study authors. Moreover, many exposure measurements are in databases (rather than study records), which we did not comprehensively review and access. We approached SYNJEM and FINJEM and asked for aggregated data- but did not receive the requested data. We expect an overlap in data between our systematic review and these exposure databases, due to our thorough search strategy including both peer-reviewed and grey literature. Future systematic reviews would benefit from updating the current work with these data (if and when feasible). Finally, our searches may have missed studies published in languages other than English. However, we searched many electronic bibliometric and grey literature databases using a comprehensive search strategy and consulted additional experts, which lead to us identifying only few additional eligible study records.

Taken together, the current systematic review can be regarded as an important starting point for a global source, where prevalence and level of occupational exposure to silica, asbestos and coal dust can be

Study or Subgroup	Levels of exposure	SE	Weight	Levels of exposure IV, Random, 95% CI
Andersson 2009	0.034	0.000815	4.7%	0.03 [0.03, 0.04]
Azari 2009 (1)	0.343	0.017068	3.2%	0.34 [0.31, 0.38]
Azari 2009 (2)	0.272	0.019807	2.9%	0.27 [0.23, 0.31]
Carneiro 2017	0.401	0.034536	1.6%	0.40 [0.33, 0.47]
Chen 2012 (3)	0.184	0.00757	4.3%	0.18 [0.17, 0.20]
Chen 2012 (4)	0.092	0.002332	4.7%	0.09 [0.09, 0.10]
Foreland 2008	0.015	0.004548	4.6%	0.01 [0.01, 0.02]
Khoza 2012 (5)	0.154	0.009893	4.1%	0.15 [0.13, 0.17]
Khoza 2012 (6)	0.106	0.035913	1.6%	0.11 [0.04, 0.18]
Khoza 2012 (7)	0.012	0.002544	4.7%	0.01 [0.01, 0.02]
Khoza 2012 (8)	0.105	0.024489	2.4%	0.10 [0.06, 0.15]
Khoza 2012 (9)	0.042	0.007661	4.3%	0.04 [0.03, 0.06]
Oudyk 1995	0.048	0.001663	4.7%	0.05 [0.04, 0.05]
Radnoff 2014 (10)	0.02	0.005367	4.5%	0.02 [0.01, 0.03]
Radnoff 2014 (11)	0.02	0.014157	3.6%	0.02 [-0.01, 0.05]
Radnoff 2014 (12)	0.09	0.029056	2.0%	0.09 [0.03, 0.15]
Rokni 2016 (13)	0.339	0.038631	1.4%	0.34 [0.26, 0.41]
Rokni 2016 (14)	0.16	0.03857	1.4%	0.16 [0.08, 0.24]
Rokni 2016 (15)	0.203	0.052259	0.9%	0.20 [0.10, 0.31]
Rokni 2016 (16)	0.238	0.049108	1.0%	0.24 [0.14, 0.33]
Rokni 2016 (17)	0.173	0.023494	2.5%	0.17 [0.13, 0.22]
Rokni 2016 (18)	0.308	0.040999	1.3%	0.31 [0.23, 0.39]
Rokni 2016 (19)	0.115	0.030779	1.9%	0.12 [0.05, 0.18]
Sayler 2018	0.005	0.00025	4.7%	0.01 [0.00, 0.01]
Scarselli 2014 (20)	0.017	0.001489	4.7%	0.02 [0.01, 0.02]
Scarselli 2014 (21)	0.007	0.000538	4.7%	0.01 [0.01, 0.01]
Scarselli 2014 (22)	0.01	0.001095	4.7%	0.01 [0.01, 0.01]
Yassin 2005	0.073	0.001558	4.7%	0.07 [0.07, 0.08]
Zarei 2017	0.245	0.006721	4.4%	0.24 [0.23, 0.26]
Zhuang 2001	0.058	0.01093	4.0%	0.06 [0.04, 0.08]
Total (95% CI)			**100.0%**	**0.10 [0.09, 0.11]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 7653.28$, $df = 29$ ($P < 0.00001$); $I^2 = 100\%$
Test for overall effect: $Z = 18.02$ ($P < 0.00001$)



Footnotes
(1) ISIC 24
(2) ISIC 23
(3) ISIC 23, 1960-1980
(4) ISIC 23, 1981-2000
(5) ISIC 24
(6) ISIC 23, sandstone work including sandblasting
(7) ISIC 32, ceramics/potteries/refractories work
(8) ISIC 23, sandstone work including sandblasting
(9) ISIC 32, ceramics/potteries/refractories work
(10) ISIC 23
(11) ISIC 24
(12) ISIC 32
(13) ISIC 24
(14) ISIC 23, brick manufacturing
(15) ISIC 23, asphalt manufacturing
(16) ISIC 23, sand blasting
(17) ISIC 32, stone cutters and millers
(18) ISIC 23, brick manufacturing
(19) ISIC 23, glass manufacturing
(20) ISIC 23
(21) ISIC 24
(22) ISIC 31

Fig. 5. Main *meta*-analysis, level of occupational exposure to silica, Manufacturing ISIC 20, 23–25, 27, 31–32.

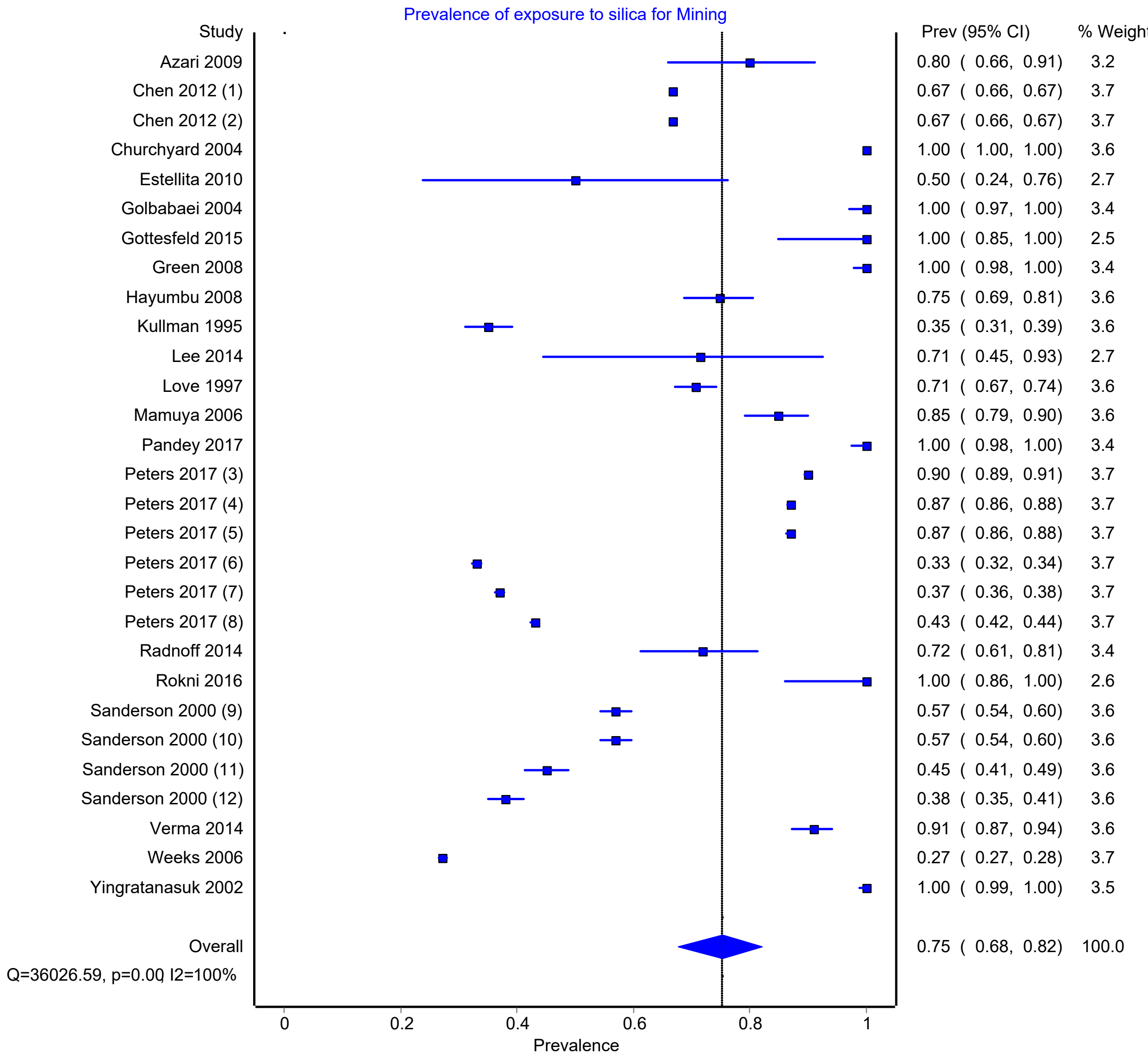


Fig. 6. Main *meta*-analysis, prevalence of occupational exposure to silica, Mining ISIC 05, 07, 08.

assessed, and we are not aware of any other systematic review with *meta*-analysis on this topic.

We included studies with information that enabled us to assess prevalence of exposure, where exposure was dichotomised into no (or low) versus any (or high) occupational exposure. Furthermore, we also included studies on level of occupational exposures. In most studies we defined exposure as measurements above the LOD and used measurements and not individuals as the unit of analysis.

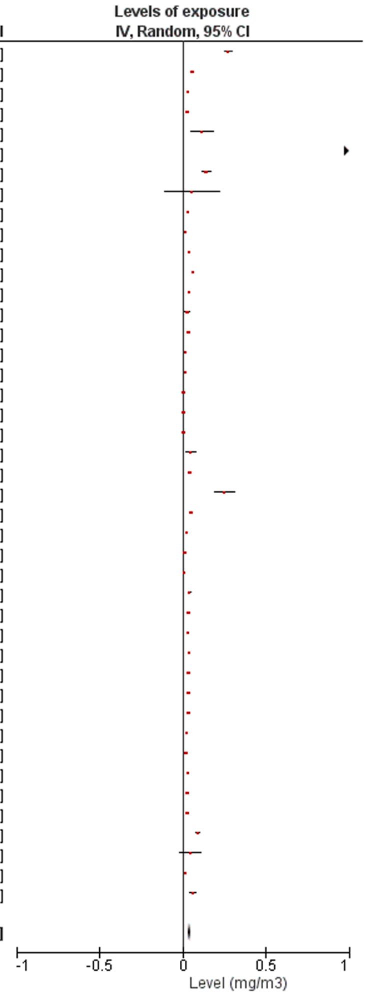
The LOD changes over time and depends on several factors, such as sampling duration, sampling method, the LOD of the analytical methods, and the sampling strategy, and therefore the LOD varies across studies. Still, we anticipate the LOD to be a good indication of no (or low) exposure in a given study. In few studies with no information on the LOD we defined exposure as measurements above an OEL. This likely resulted in an underestimation of the prevalence of exposure given that the LOD is generally well below the OEL. We included these studies to cover as many WHO regions and countries as possible. Only few studies used an OEL and we, therefore, do not anticipate this to have had a noteworthy impact on the overall prevalence found for occupational exposure to silica, asbestos and coal dust, respectively.

Occupational exposure prevalence (often termed exposure probability) is, in the vast majority of epidemiological studies on health effects, based on silica, asbestos or coal dust internal or external job exposure matrices or exposure modelling. We found high occupational exposure prevalences for silica in Construction (89%) and Manufacturing (85%). Exposure prevalences for construction workers have been assessed from different external job exposure matrices, for example FINJEM (Kauppinen et al. 2013), MATGENE (Fevotte et al. 2011) and MATEMESP (Garcia et al. 2013). These job exposure matrices provide exposure prevalences between 14 and 90% for main manual construction job titles (construction and maintenance and building construction laborers) and between 40 and 90% for main manufacturing job titles (Ore and metal furnace operators, Glass and ceramics kiln and related machine operators, Mineral-ore- and stone-processing-plant operators). This exemplifies that our pooled prevalence estimates fall on the high end compared to occupational exposure prevalence estimates from other sources. Of note, our definition of exposure (above limit of detection) will result in higher prevalences of exposures compared to studies where different occupational exposure limits have been used to define exposure.

We assumed that the proportion of measurements where exposure above LOD was found reflects the proportion of exposed individuals (workers). For example, for silica, within the industrial sectors that comprise Construction, we assume 89% of the source population of

Study or Subgroup	Levels of exposure	SE	Weight	Levels of exposure IV, Random, 95% CI
Azari 2009	0.275	0.012498	2.0%	0.28 [0.25, 0.30]
Chen 2012 (1)	0.057	0.000045	2.7%	0.06 [0.06, 0.06]
Chen 2012 (2)	0.032	0.000033	2.7%	0.03 [0.03, 0.03]
Churchyard 2004	0.028	0.001353	2.6%	0.03 [0.03, 0.03]
Gottesfeld 2015 (3)	0.117	0.035473	0.7%	0.12 [0.05, 0.19]
Gottesfeld 2015 (4)	14.22	4.341232	0.0%	14.22 [5.71, 22.73]
Kreiss 1996 (5)	0.142	0.012816	1.9%	0.14 [0.12, 0.17]
Kreiss 1996 (6)	0.057	0.083626	0.2%	0.06 [-0.11, 0.22]
Kreiss 1996 (7)	0.03	0.00281	2.6%	0.03 [0.02, 0.04]
Kreiss 1996 (8)	0.018	0.00201	2.6%	0.02 [0.01, 0.02]
Kullman 1995 (9)	0.04	0.001524	2.6%	0.04 [0.04, 0.04]
Kullman 1995 (10)	0.06	0.003512	2.6%	0.06 [0.05, 0.07]
Kullman 1995 (11)	0.04	0.001832	2.6%	0.04 [0.04, 0.04]
Mamuya 2006	0.027	0.006137	2.5%	0.03 [0.01, 0.04]
Peters 2017 (12)	0.037	0.000499	2.7%	0.04 [0.04, 0.04]
Peters 2017 (13)	0.017	0.000199	2.7%	0.02 [0.02, 0.02]
Peters 2017 (14)	0.016	0.000236	2.7%	0.02 [0.02, 0.02]
Peters 2017 (15)	0.007	0.000092	2.7%	0.01 [0.01, 0.01]
Peters 2017 (16)	0.006	0.000063	2.7%	0.01 [0.01, 0.01]
Peters 2017 (17)	0.006	0.000059	2.7%	0.01 [0.01, 0.01]
Radnoff 2014	0.048	0.01613	1.7%	0.05 [0.02, 0.08]
Rando 2001	0.042	0.000669	2.7%	0.04 [0.04, 0.04]
Rokni 2016	0.253	0.029896	0.9%	0.25 [0.19, 0.31]
Sanderson 2000 (18)	0.051	0.003594	2.6%	0.05 [0.04, 0.06]
Sanderson 2000 (19)	0.026	0.001758	2.6%	0.03 [0.02, 0.03]
Sanderson 2000 (20)	0.012	0.001091	2.7%	0.01 [0.01, 0.01]
Sanderson 2000 (21)	0.008	0.000558	2.7%	0.01 [0.01, 0.01]
Verma 2014	0.04	0.003035	2.6%	0.04 [0.03, 0.05]
WattsJr 2012 (22)	0.037	0.00064	2.7%	0.04 [0.04, 0.04]
WattsJr 2012 (23)	0.032	0.000883	2.7%	0.03 [0.03, 0.03]
WattsJr 2012 (24)	0.039	0.00072	2.7%	0.04 [0.04, 0.04]
WattsJr 2012 (25)	0.037	0.002813	2.6%	0.04 [0.03, 0.04]
WattsJr 2012 (26)	0.036	0.000356	2.7%	0.04 [0.04, 0.04]
WattsJr 2012 (27)	0.035	0.000471	2.7%	0.04 [0.03, 0.04]
WattsJr 2012 (28)	0.023	0.000195	2.7%	0.02 [0.02, 0.02]
WattsJr 2012 (29)	0.021	0.000266	2.7%	0.02 [0.02, 0.02]
WattsJr 2012 (30)	0.031	0.000229	2.7%	0.03 [0.03, 0.03]
WattsJr 2012 (31)	0.029	0.000327	2.7%	0.03 [0.03, 0.03]
Weeks 2006	0.027	0.000235	2.7%	0.03 [0.03, 0.03]
Yassin 2005	0.091	0.004531	2.5%	0.09 [0.08, 0.10]
Zhuang 2001 (32)	0.047	0.032749	0.8%	0.05 [-0.02, 0.11]
Zhuang 2001 (33)	0.017	0.000892	2.7%	0.02 [0.02, 0.02]
Zhuang 2001 (34)	0.062	0.009349	2.2%	0.06 [0.04, 0.08]
Total (95% CI)			**100.0%**	**0.04 [0.03, 0.05]**

Heterogeneity: Tau² = 0.00; Chi² = 750564.42, df = 42 (P < 0.00001); I² = 100%
Test for overall effect: Z = 12.05 (P < 0.00001)



Footnotes
(1) ISIC 07,1960-1980
(2) ISIC 07, 1981-2000
(3) ISIC 07, artisanal Small-Scale Gold Mining 2014
(4) ISIC 07, artisanal Small-Scale Gold Mining 2014
(5) ISIC 07, mining of metal ores 1974-82
(6) ISIC 07, mining of metal ores 1974-82
(7) ISIC 07, mining of metal ores 1974-82
(8) ISIC 07, mining of metal ores 1974-82
(9) ISIC 08, stone mining and milling operations
(10) ISIC 08, stone mining and milling operations
(11) ISIC 08, stone mining and milling operations
(12) ISIC 07, 1986-1990
(13) ISIC 07, 1996-2000
(14) ISIC 07, 2001-2005
(15) ISIC 07, 2006-2010
(16) ISIC 07, 2011-2015
(17) ISIC 08, 1974-1979
(18) ISIC 08, 1974-1979
(19) ISIC 08, 1980-1984
(20) ISIC 08, 1985-1988
(21) ISIC 08, 1989-1996
(22) ISIC 07, 1993-2004
(23) ISIC 07, 2005-2010
(24) ISIC 08, 1993-2004, stone mining
(25) ISIC 08, 2005-2010, stone mining
(26) ISIC 08, 1993-2004, crushing of limestone
(27) ISIC 08, 2005-2010, crushing of limestone
(28) ISIC 08, 1993-2004, sand and gravel work
(29) ISIC 08, 2005-2010, sand and gravel work
(30) ISIC 08, 1993-2004, non-metal mining
(31) ISIC 08, 2005-2010, non-metal mining
(32) ISIC 07, Tungsten mining
(33) ISIC 07, Tin mining
(34) ISIC 07, Iron/cupper mining

Fig. 7. Main *meta*-analysis, level of occupational exposure to silica, Mining ISIC 05, 07, 08.

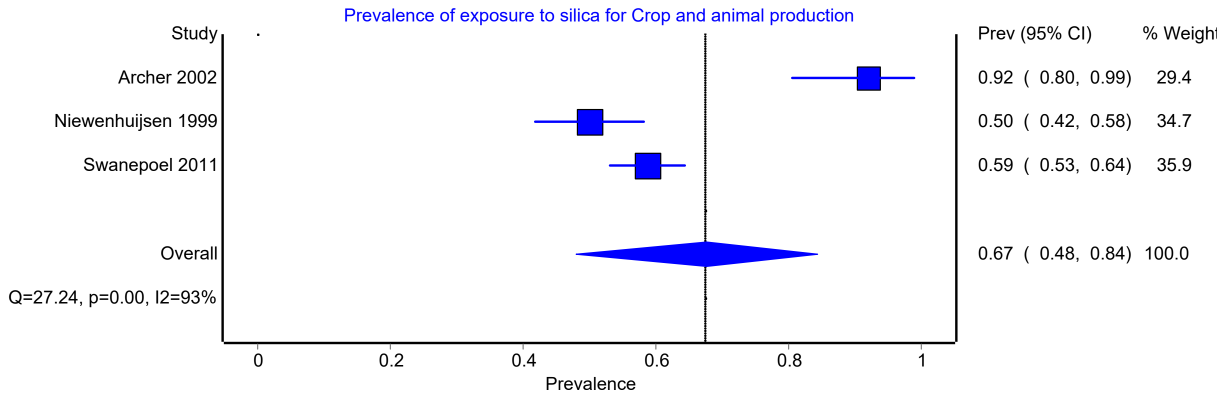


Fig. 8. Main *meta*-analysis, prevalence of occupational exposure to silica, Crop and animal production, hunting and related service activities ISIC 01.

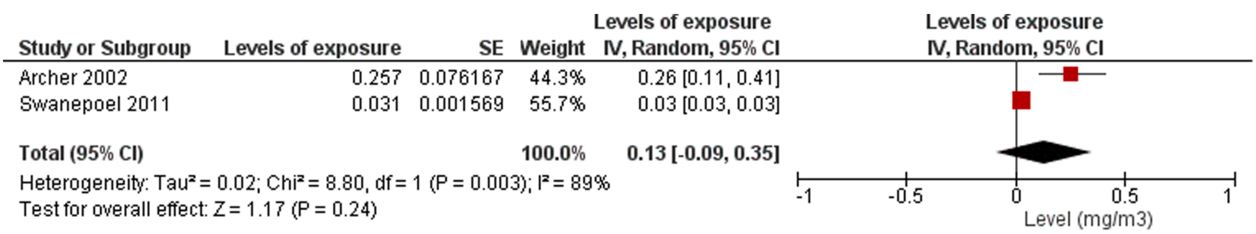


Fig. 9. Main *meta*-analysis, level of occupational exposure to silica, Crop and animal production, hunting and related service activities ISIC 01.

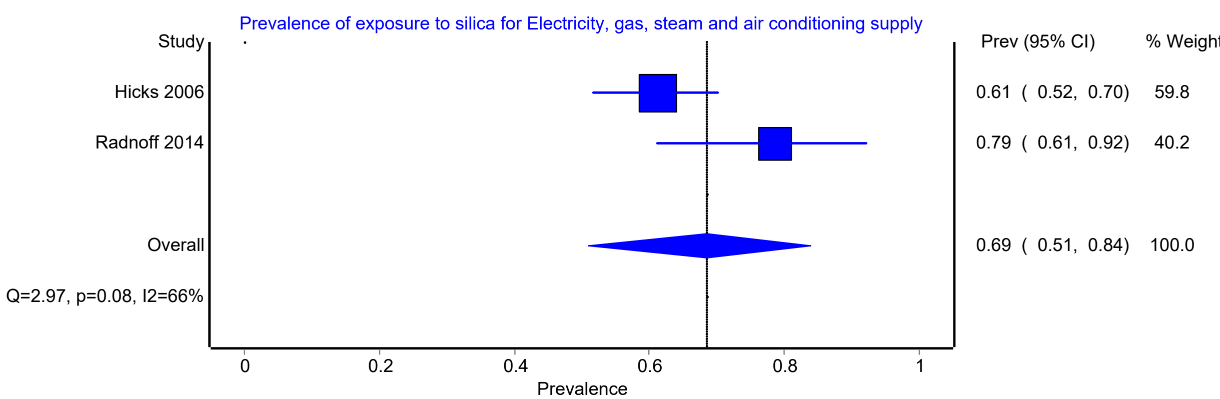


Fig. 10. Main *meta*-analysis, prevalence of occupational exposure to silica, Electricity, gas, steam and air conditioning supply ISIC 35.

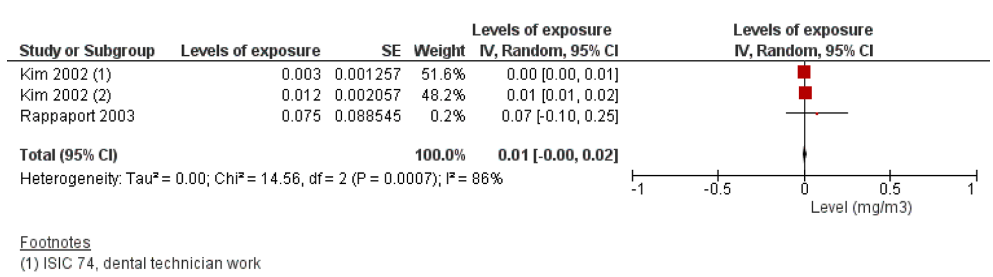


Fig. 11. Main *meta*-analysis, level of occupational exposure to silica, Professional, scientific and technical activities ISIC 71, 74.

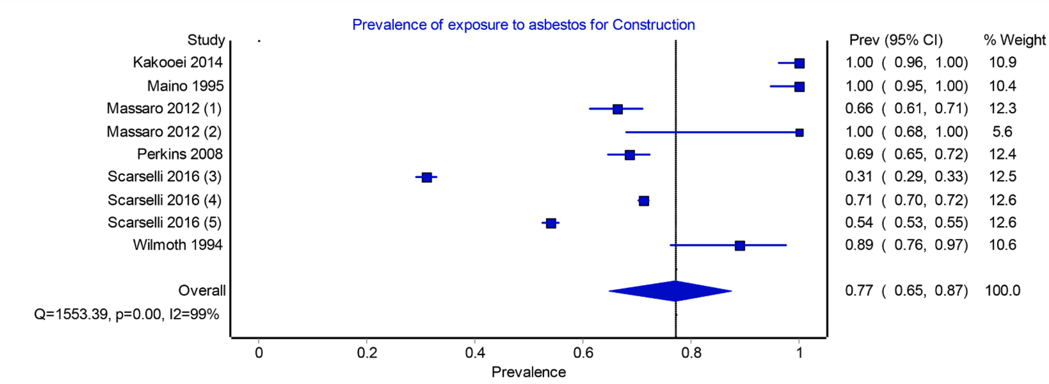


Fig. 12. Main *meta*-analysis, prevalence of occupational exposure to asbestos, Construction ISIC 41, 43, 45.

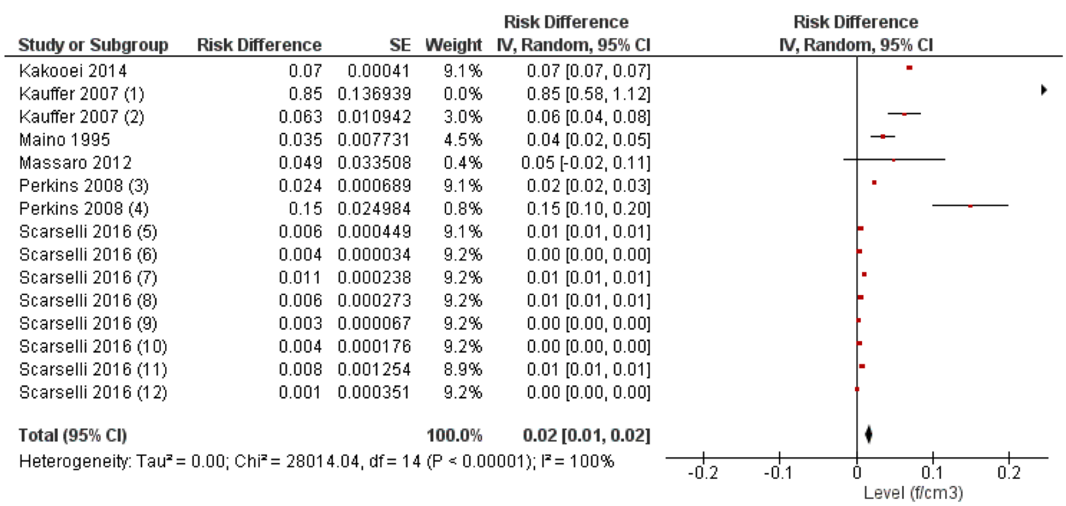


Fig. 13. Main *meta*-analysis, level of occupational exposure to asbestos, Construction ISIC 41, 43, 45.

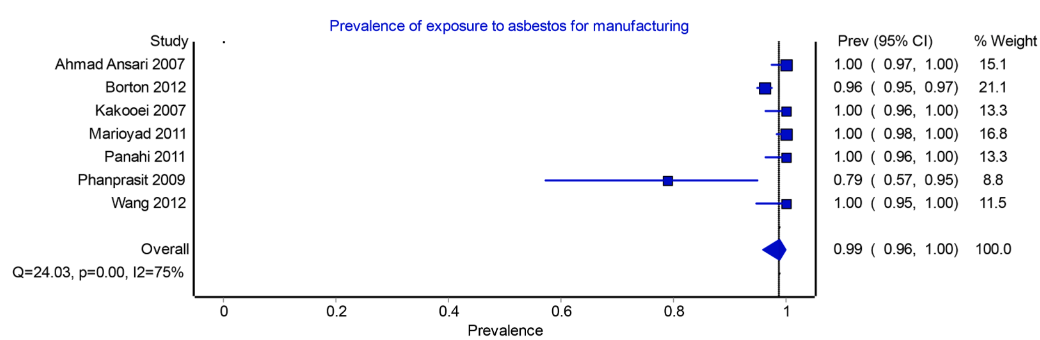


Fig. 14. Main *meta*-analysis, prevalence of occupational exposure to asbestos, Manufacturing ISIC 13, 23, 24, 29, 30.

workers to be exposed. By doing so we assumed that the measured sample was a random sample of the target population (i.e., all workers), and eventually the source population (i.e., also all workers). This may be a reasonable assumption for some industrial sectors, for example mining and quarrying where we expected that most silica measurements originated from routine sampling involving most workers, and we expected a large proportion of mineworkers to be occupationally exposed to silica dust. For other industries, such as farming, we anticipated a smaller fraction to be occupationally exposed to silica, and furthermore a worst-case sampling strategy was often used. Therefore, we present the estimates of prevalence and level by industrial sector. Still, we have raised at least serious concerns regarding external validity (in the QoE-SPEO downgrade domain of indirectness (Pega et al. 2022b)) for the current bodies of evidence for most industrial sectors, mostly due to the fact that measurements are currently unavailable for industrial subsectors in which exposure to the occupational risk factor is not expected to occur. This lack of evidence for workers in all or some of the unexposed industrial subsectors for an industrial sector will have led to an overestimation of the prevalence and level of exposure at the level of the entire population of workers for the industrial sector in our *meta*-analyses. Additionally, we considered risk of bias from selection into the study during the risk of bias and quality of evidence assessments, as this

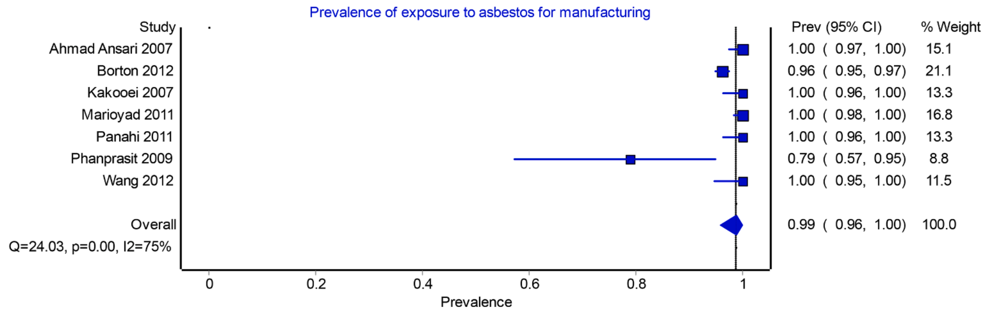


Fig. 15. Main *meta*-analysis, level of occupational exposure to asbestos, Manufacturing ISIC 13, 23, 24, 29, 30.

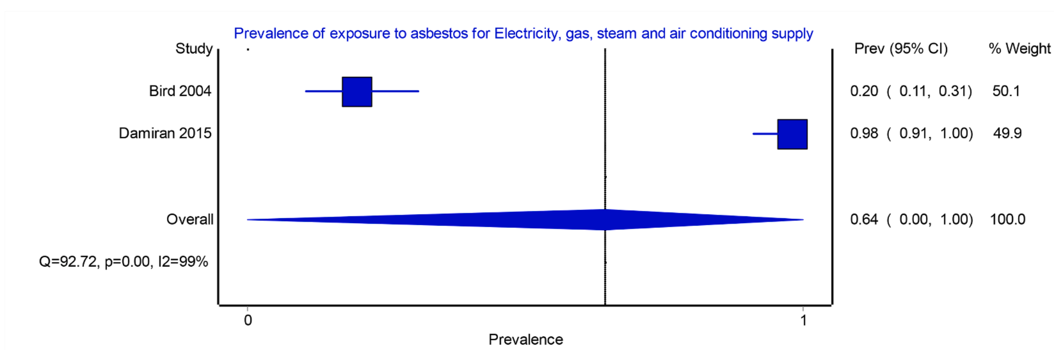


Fig. 16. Main *meta*-analysis, prevalence of occupational exposure to asbestos, Electricity, gas, steam and air conditioning supply ISIC 35.

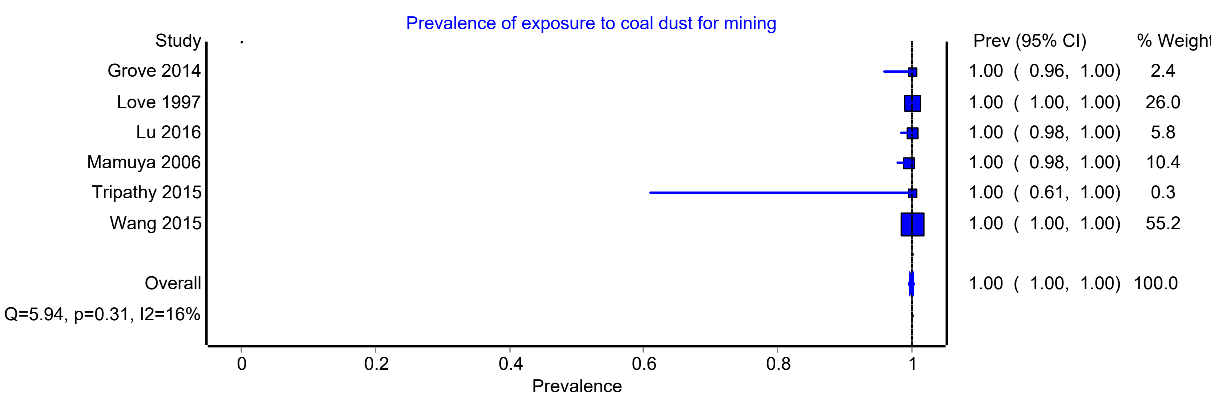


Fig. 17. Main *meta*-analysis, prevalence of occupational exposure to coal dust, Mining of coal and lignite ISIC 05.

was a risk of bias domain of prime concern across the occupational exposures.

Day-to-day variability in exposure is the largest variance component of airborne occupational measurements (Kromhout et al. 1993), which can only be assessed if more than one measurement per person is available. Repeated measurements were available in some of the included studies, and therefore, the day-to-day variability is to some extent included in the exposure prevalence and level estimates we present in this systematic review. We presented and included repeated measurements as independent, individual measurements, and therefore the day-to-day variability cannot be separated out, and we are not sure whether this approach has resulted in underestimation or overestimation of the true prevalence and level of occupational exposure.

We only included studies with objective measurements of occupational exposure to silica, asbestos and coal dust, i.e., quantitative samples of dust and/or fibres collected by an expert using appropriate technologies. This strict requirement allowed us to take the national, regional and global exposure assessment one step further, based on the estimates of exposure prevalence and level on measurements data from several WHO regions and from the most relevant industrial sectors. This is an improvement over the CAREX initiative which modelled estimates for number of workers occupationally exposed to asbestos and silica, estimated via proxy of occupation and/or industrial sector. Additionally, they only provided information from European Union and a few other countries (Kauppinen et al. 2000; Blanco-Romero et al. 2011; Peters et al. 2015).

Few studies provided data disaggregated by sex and age group, preventing subgroup analyses by sex and age group, and consequently such disaggregated data are unavailable for the WHO/ILO Joint Estimates. Overall, only few studies reported female workers to be present in the study population; however, most studies did not provided information about the sex distribution of the exposure prevalence and/or level.

Our systematic review is also limited to data derived mainly from the formal economy. While we also searched for data from the informal

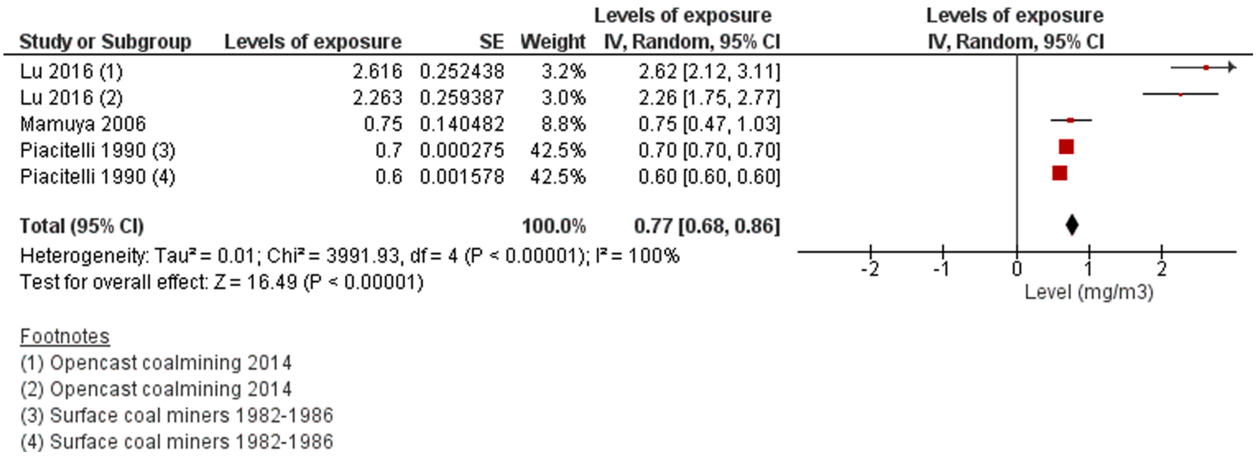


Fig. 18. Main *meta*-analysis, level of occupational exposure to coal dust, Mining of coal and lignite ISIC 05.

economy, we were unable to find eligible studies (apart from one asbestos study and one coal dust study where the type of economy was uncertain). Therefore, the results of this systematic review are mainly representative for workers in the formal economy.

When personal sampling was available, we assessed the occupational exposure prevalence and level based on personal samples only. In few included studies where only stationary sampling was available, we used these measurements in the same way as the personal measurements. This may underestimate the prevalence and level, as stationary measurements in general underestimate personal exposures at the workplace. However, this was the case in very few included studies only, and therefore we do not think this had a noteworthy impact on our prevalence and level estimates.

Neither *meta*-analysis by year or decade, nor time trend analyses were included in this systematic review (Mandrioli et al. 2018). Thus, the result of the current systematic review should be regarded as grand means of prevalences and levels for occupational exposure to silica, asbestos and coal dust for the decades of 1960–2015. Time trends will be an important component of future work on national, regional and global occupational dust and fibre exposure prevalences and levels.

In the literature, crystalline silica and quartz are often used synonymously, and in this systematic review we have not distinguished between crystalline silica and quartz, which is the main component of crystalline silica. We consequently judge our results to be valid for assessment of both quartz and crystalline silica.

We only included studies using exposure assessment based on active filter sampling and gravimetric assessment followed by technical analysis as our gold standard. We thus did not expect any information bias. Most measurements were full shift measurements, and only few included studies reported shorter sampling durations (below 4 hours).

In most included studies the silica content was measured in respirable dust. Most coal dust studies measured respirable coal dust, too. The respirable dust fraction refers to the particle distribution that can reach the lower airways and is therefore highly relevant for silicosis and coal workerś pneumoconiosis. In most studies the silica content of the respirable dust was estimated by X-ray diffraction or infrared spectroscopy with only a few exceptions that we believe did not affect the overall results.

In most studies counting of asbestos fibres was done using phase-contrast microscopy (PCM), but a few studies used the more sensitive method of scanning electron microscopy (SEM). A study that used both methods (Kakooei and Normohammadi 2014) found that the fibre concentration was twice as high for SEM than for PCM. Therefore, absolute levels of occupational exposure to asbestos fibres were likely underestimated. As most existing health effects studies with dose–response data have used PCM measurements we do not believe this caused noteworthy bias.

Performing *meta*-analyses for exposure prevalence we used a double arcsine transformation, enabling us to deal with skewed data. However, it was not possible to carry out tests of subgroup differences for these analyses. In the absence of a statistical test, we used the point estimates and 95% CIs to judge differences between subgroups. We acknowledge that this judgment-based approach has limitations.

To the best of our knowledge, occupational exposure data for level of silica, asbestos and coal dust is best described by a log-normal distribution. In the *meta*-analysis of exposure levels, we therefore used geometric mean (GM) and geometric standard deviation (GSD), either directly or after transformation from AM, SD and range (Zwillinger 2000; Lavoué et al. 2007). For some studies we assumed the median value to reflect GM, and we used the range in GMs to assess GM if the distribution was narrow (ratio between highest and lowest exposure $\leq$ 2). This allowed us to include a large proportion of the studies in the *meta*-analyses for level. We judged this adjustment to be minor and to have negligible impact on the results. All *meta*-analyses used a weighted average from a random-effects model based on the inverse variance method. Since, our data were not normally distributed they cannot be well represented by arithmetic means and symmetric confidence intervals. Some of the lower 95% CI limits for pooled estimates of exposure level are negative, which is impossible as there is no negative exposure. This is due to the methods used, that only allowed us to produce symmetric confidence intervals, when the lower 95% CI limit should be capped at 0. This will have led to spurious results in the pooled estimates of very small and heterogeneous subgroups. However, by using the standard error of the confidence interval furthest away from each point estimate in the *meta*-analyses, we will have overestimated uncertainty, rather than underestimated it. We have been unable to identify a better approach for this kind of *meta*-analysis and believe this is a current methodological gap for *meta*-analyses of levels of exposure. Future methodological work is required to address this gap in systematic reviews in Exposure Science.

A further gap we identified for systematic reviews of prevalences and levels is the lack of an easy to interpret plot to assess publication bias for skewed data.

We emphasize again that this systematic review identified no population-based studies that were eligible for inclusion. The included studies did not sample workers from all subsectors within the industrial sectors of interest, nor did they sample the entire worker population within the subsectors that they did sample; instead they sampled those subsectors and workers within these who were likely to be occupationally exposed to dusts or fibers, respectively. In other words, and importantly, we consider it highly likely that unexposed workers were systematically selected out of the included studies and are therefore systematically underrepresented in the current bodies of evidence available for synthesis in this systematic review. Therefore, we judge the

Table 21
Subgroup *meta*-analysis, prevalence and level of occupational exposure to silica by industrial sector across WHO regions.

Industrial sector	WHO Region	Prevalence (95% confidence interval)	Numbers of measures (entries) of prevalence of exposure, studies, and countries, and I^2	Level mg/m^3 (95% confidence interval)	Numbers of measures (entries) of level of exposure, studies, and countries, and I^2	P value for test of subgroup differences for levels [a]
Construction	Africa	1.00 (0.97 to 1.00)	1 entry from 1 study,1 country	0.01 (0.01 to 0.01)	1 entry from 1 study, 1 country	P < 0.00001
	Americas	0.87 (0.79 to 0.93)	10 entries from 5 studies, 2 countries, I^2 86%	0.04 (0.02 to 0.07)	8 entries from 4 studies, 2 countries, I^2 92%	
	Eastern Mediterranean	0.94 (0.81 to 1.00)	4 entries from 3 studies, 1 country, I^2 87%	0.18 (0.12 to 0.24)	4 entries from 3 studies, 1 country, I^2 97%	
	Europe	0.87 (0.79 to 0.94)	9 entries from 8 studies, 3 countries, I^2 93%	0.03 (0.02 to 0.04)	12 entries from 8 studies, 4 countries, I^2 99%	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	-[b]	-[b]	-[b]	-[b]	
Manufacturing	Africa	1.00 (0.99 to 1.00)	4 entry from 2 studies, 1 country, I^2 0%	0.08 (0.02 to 0.14)	5 entries from 1 study, 1 country, I^2 98%	P < 0.00001
	Americas	0.87 (0.79 to 0.93)	7 entries from 5 studies, 2 countries, I^2 83%	0.07 (0.05 to 0.10)	6 entries from 4 studies, 3 countries, I^2 98%	
	Eastern Mediterranean	0.96 (0.91 to 1.00)	12 entries from 4 studies, 1 country, I^2 79%	0.24 (0.20 to 0.28)	10 entries from 3 studies, 1 country, I^2 88%	
	Europe	0.65 (0.41 to 0.87)	9 entries from 7 studies, 7 countries, I^2 100%	0.02 (0.00 to 0.03)	5 entries from 3 studies, 3 countries, I^2 99%	
	South-East Asia	0.81 (0.00 to 1.00)	2 entries from 2 studies, 2 countries, I^2 99%	0.01 (0.00 to 0.01)	1 entry from 1 study, 1 country	
	Western Pacific	0.61 (0.43 to 0.77)	5 entries from 4 studies, 2 countries, I^2 100%	0.11 (0.05 to 0.18)	3 entries from 2 studies, 1 country, I^2 99%	
Mining	Africa	0.93 (0.73 to 1.00)	4 entries from 4 studies, 3 countries, I^2 98%	0.04 (0.01 to 0.06)	4 entries from 3 studies, 2 countries, I^2 82%	P < 0.00001
	Americas	0.53 (0.39 to 0.66)	9 entries from 6 studies, 3 countries, I^2 99%	0.04 (0.03 to 0.04)	26 entries from 9 studies, 2 countries, I^2 100%	
	Eastern Mediterranean	0.95 (0.78 to 1.00)	3 entries from 3 studies, 1 country, I^2 88%	0.27 (0.25 to 0.29)	2 entries from 2 studies, 1 country, I^2 0%	
	Europe	0.71 (0.67 to 0.74)	1 entry from 1 study, 1 country	-[b]	-[b]	
	South-East Asia	1.00 (0.99 to 1.00)	3 entries from 3 studies, 2 countries, I^2 0%	-[b]	-[b]	
	Western Pacific	0.66 (0.53 to 0.78)	9 entries from 3 studies, 3 countries, I^2 100%	0.03 (0.01 to 0.04)	9 entries from 3 studies, 2 countries, I^2 100%	
Crop and animal production	Africa	0.59 (0.53 to 0.64)	1 entry from 1 study, 1 country	0.03 (0.03 to 0.03)	1 entry from 1 study, 1 country	P = 0.003
	Americas	0.73 (0.23 to 1.00)	2 entries from 2 studies, 1 country, I^2 96%	0.26 (0.11 to 0.41)	1 entry from 1 study, 1 country	
	Eastern Mediterranean	-[b]	-[b]	-[b]	-[b]	
	Europe	-[b]	-[b]	-[b]	-[b]	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	-[b]	-[b]	-[b]	-[b]	
Electricity, gas, steam and air conditioning supply	Africa	-[b]	-[b]	-[b]	-[b]	NA
	Americas	0.69 (0.51 to 0.84)	2 entries from 2 studies, 2 countries, I^2 66%	0.02 (-0.01 to 0.06)	1 entry from 1 study, 1 country	
	Eastern Mediterranean	-[b]	-[b]	-[b]	-[b]	
	Europe	-[b]	-[b]	-[b]	-[b]	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	-[b]	-[b]	-[b]	-[b]	
Professional, scientific and technical activities	Africa	-[b]	-[b]	-[b]	-[b]	P = 0.45
	Americas	-[b]	-[b]	0.07 (-0.10 to 0.25)	1 entry from 1 study, 1 country	
	Eastern Mediterranean	-[b]	-[b]	-[b]	-[b]	
	Europe	-[b]	-[b]	-[b]	-[b]	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	0.99 (0.96 to 1.00)	1 entry from 1 study, 1 country	0.01 (-0.00 to 0.02)	2 entries from 1 study, 1 country	

[a] P value for test of subgroup differences is shown for level estimates only as it was not possible to generate this for the subgroup analyses for prevalence.
[b] No data available.

pooled estimates from the *meta*-analyses presented here to overestimate both prevalences and levels of exposure within industrial sectors. One avenue to seek to address this overestimation would be to develop a new method to adjust for non-representative measurement of the industrial sectors of interest and the workers within the selected subsectors that were sampled. However, we judged this to be an infeasible option because the global input measurements data required for such a new estimation model are unavailable, such as the proportion of workers per industrial subsector of interest and the proportion of exposed and unexposed workers by subsector. Since adjustment for the selection bias in the included studies though modelling was infeasible, we addressed the overestimation of exposure prevalences and levels in the QoE-SPEO quality of evidence assessments (Pega et al. 2022b), consistent with previous WHO/ILO systematic reviews of occupational exposure

Table 22
Subgroup *meta*-analysis, prevalence and level of occupational exposure to asbestos by industrial sector across WHO regions.

Industrial sector	WHO Region	Prevalence (95% confidence interval)	Numbers of measures (entries) of prevalence of exposure, studies, and countries, and I^2	Level f/ml (95% confidence interval)	Numbers of measures (entries) of level of exposure, studies, and countries, and I^2	P value for test of subgroup differences for levels [a]
Construction	Africa	-[b]	-[b]	-[b]	-[b]	P < 0.00001
	Americas	0.78 (0.57 to 0.96)	2 entries from 2 studies, 1 country, I^2 87%	0.08 (-0.04 to 0.21)	2 entries from 1 study, 1 country, I^2 96%	
	Eastern Mediterranean	1.00 (0.96 to 1.00)	1 entry from 1 study, 1 country	0.07 (0.07 to 0.07)	1 entry from 1 study, 1 country	
	Europe	0.70 (0.54 to 0.85)	6 entries from 3 studies, 1 country, I^2 100%	0.01 (0.00 to 0.01)	12 entries from 4 studies, 2 countries, I^2 99%	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	-[b]	-[b]	-[b]	-[b]	
Manufacturing	Africa	-[b]	-[b]	-[b]	-[b]	P < 0.00001
	Americas	0.96 (0.95 to 0.97)	1 entry from 1 study, 1 country	-[b]	-[b]	
	Eastern Mediterranean	1.00 (0.99 to 1.00)	3 entries from 3 studies, 1 country, I^2 0%	0.07 (0.03 to 0.12)	2 entries from 2 studies, 1 country, I^2 96%	
	Europe	-[b]	-[b]	0.20 (0.08 to 0.31)	6 entries from 1 study, 1 country, I^2 98%	
	South-East Asia	0.93 (0.62 to 1.00)	2 entries from 2 studies, 2 countries, I^2 89%	2.18 (-2.09 to 6.45)	2 entries from 2 study, 2 countries, I^2 99%	
	Western Pacific	1.00 (0.95 to 1.00)	1 entry from 1 study, 1 country	-[b]	-[b]	
Other mining and quarrying	Africa	-[b]	-[b]	-[b]	-[b]	NA
	Americas	-[b]	-[b]	-[b]	-[b]	
	Eastern Mediterranean	-[b]	-[b]	-[b]	-[b]	
	Europe	0.85 (0.77 to 0.91)	1 entry from 1 study, 1 country	0.01 (0.01 to 0.02)	1 entry from 1 study, 1 country	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	-[b]	-[b]	-[b]	-[b]	
Electricity, gas, steam and air conditioning supply	Africa	-[b]	-[b]	-[b]	-[b]	NA
	Americas	0.20 (0.11 to 0.31)	1 entry from 1 study, 1 country	-[b]	-[b]	
	Eastern Mediterranean	-[b]	-[b]	-[b]	-[b]	
	Europe	-[b]	-[b]	-[b]	-[b]	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	0.98 (0.91 to 1.00)	1 entry from 1 study, 1 country	0.40 (0.21 to 0.58)	1 entry from 1 study, 1 country	
Water supply, sewerage, waste management and remediation	Africa	-[b]	-[b]	-[b]	-[b]	NA
	Americas	-[b]	-[b]	-[b]	-[b]	
	Eastern Mediterranean	-[b]	-[b]	-[b]	-[b]	
	Europe	-[b]	-[b]	0.00 (0.00 to 0.00)	1 entry from 1 study, 1 country	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	-[b]	-[b]	-[b]	-[b]	

[a] P value for test of subgroup differences is shown for level estimates only as it was not possible to generate this for the subgroup analyses for prevalence.
[b] No data available.

prevalences in the series, produced as part of the WHO/ILO Joint Estimates (Hulshof et al. 2021a; Teixeira et al. 2021b). Under the QoE-SPEO domain of Indirectness, we added downgrading of the quality of evidence for all bodies of evidence for all exposure prevalences and levels for all industrial sectors by one level for the serious concerns we had for the lack of evidence from population-based studies. This resulted in the Working Group having at least serious concerns regarding indirectness (and therefore external validity) for these bodies of evidence, especially when these bodies of evidence are applied to assign exposure to the workers' population to produce official health estimates of national, regional and global occupational risk factor exposures and their attributable burden of disease. The only exception was that we did not downgrade the quality of evidence in this way for the prevalence and level of occupational exposure to coal dust within the industrial sector of Mining of coal and lignite, as we judged the included studies to cover all relevant industrial subsectors, reducing our concerns for indirectness.

This systematic review was a global effort that brought together experts from international organizations, national governments (including those of Bulgaria, Denmark, People's Republic of China, South Africa, and Thailand), and research agencies (including academies of science and universities). Policy staff, clinical practitioners and academic experts collaborated, ensuring broad applicability and suitability of the systematic review and its findings. The systematic review provides the exposure scientific evidence base needed for WHO and ILO to consider producing global health estimates: the WHO/ILO Joint Estimates.

6. Use of evidence for burden of disease estimation

This systematic review and *meta*-analysis was conducted by WHO and ILO, supported by a large number of individual experts, for the development of the WHO/ILO Joint Estimates. More specifically, it provides a crucial evidence base for both organizations to consider producing estimates of the burden of silicosis, asbestosis, and coal workers' pneumoconiosis attributable to occupational exposure to silica, asbestos and coal dust, respectively. This systematic review found a large body of evidence from a large number of occupational exposure studies, especially for silica, across all WHO regions. Some of the bodies

Table 23
Subgroup *meta*-analysis, prevalence and level of occupational exposure to coal dust by industrial sector across WHO regions.

Industrial sector	WHO Region	Prevalence (95% confidence interval)	Numbers of measures (entries) of prevalence of exposure, studies, and countries, and I^2	Level f/ml (95% confidence interval)	Numbers of measures (entries) of level of exposure, studies, and countries, and I^2	P value for test of subgroup differences for level [a]
Mining of coal and lignite	Africa	0.99 (0.98 to 1.00)	2 entries from 2 studies, 2 countries, I^2 0%	0.75 (0.47 to 1.03)	1 entry from 1 study, 1 country	P <0.00001
	Americas	-[a]	-[a]	0.65 (0.55 to 0.75)	2 entries from 1 study, 1 country, I^2 100%	
	Eastern Mediterranean	-[a]	-[a]	-[a]	-[a]	
	Europe	1.00 (1.00 to 1.00)	1 entry from 1 study, 1 country	-[a]	-[a]	
	South-East Asia	1.00 (0.61 to 1.00)	1 entry from 1 study, 1 country	-[a]	-[a]	
	Western Pacific	1.00 (1.00 to 1.00)	2 entries from 2 studies, 1 country, I^2 0%	2.44 (2.09 to 2.80)	2 entries from 1 study, 1 country, I^2 0%	
Electricity, gas, steam and air conditioning supply	Africa	-[b]	-[b]	-[b]	-[b]	NA
	Americas	0.02 (0.00 to 0.04)	1 entry from 1 study, 1 country	0.60 (-6.95 to 8.14)	1 entry from 1 study, 1 country	
	Eastern Mediterranean	-[b]	-[b]	-[b]	-[b]	
	Europe	-[b]	-[b]	-[b]	-[b]	
	South-East Asia	-[b]	-[b]	-[b]	-[b]	
	Western Pacific	-[b]	-[b]	-[b]	-[b]	

[a] P value for test of subgroup differences is shown for level estimates only as it was not possible to generate this for the subgroup analyses for prevalence.
[b] No data available.

Table 24
Sensitivity *meta*-analysis, prevalence and level of occupational exposure to silica by industrial sector by risk of bias rating for selection of participants into the studies.

Industrial sector	Risk of bias rating for selection of participants into the studies	Prevalence (95% confidence interval)	Numbers of measures (entries) of prevalence of exposure, studies, and countries, and I^2	Level mg/m^3 (95% confidence interval)	Numbers of measures (entries) of level of exposure, studies, and countries, and I^2	P value for test of subgroup differences for level [a]
Construction	High/Probably high	0.86 (0.79 to 0.92)	15 entries from 9 studies, I^2 84%	0.08 (0.06 to 0.10)	14 entries from 9 studies, I^2 98%	P = 0.004
	Low/Probably low	0.93 (0.87 to 0.93)	9 entries from 8 studies, I^2 95%	0.04 (0.03 to 0.05)	1 entry from 7 studies, I^2 100%	
Manufacturing	High/Probably high	0.81 (0.64 to 0.95)	20 entries from 12 studies, I^2 99%	0.08 (0.07 to 0.10)	17 entries from 8 studies, I^2 99%	P < 0.0001
	Low/Probably low	0.89 (0.80 to 0.96)	19 entries from 12 studies, I^2 100%	0.14 (0.12 to 0.16)	13 entries from 6 studies, I^2 100%	
Mining	High/Probably high	0.90 (0.76 to 1.00)	8 entries from 8 studies, I^2 92%	0.08 (0.06 to 0.10)	12 entries from 6 studies, I^2 99%	P < 0.0001
	Low/Probably low	0.69 (0.60 to 0.78)	21 entries from 12 studies, I^2 100%	0.03 (0.02 to 0.04)	31 entries from 11 studies, I^2 100%	
Crop and animal production	High/Probably high	0.92 (0.80 to 0.99)	1 entry from 1 study	0.26 (0.11 to 0.41)	1 entry from 1 study	P = 0.003
	Low/Probably low	0.55 (0.46 to 0.63)	2 entries from 2 studies, I^2 66%	0.03 (0.03 to 0.03)	1 entry from 1 study	
Electricity, gas, steam and air conditioning supply	High/Probably high	0.69 (0.51 to 0.84)	2 entries from 2 studies, 2 countries	0.02 (-0.01 to 0.06)	2 entries from 2 studies, 2 countries	NA
	Low/Probably low	-[b]	-[b]	-[b]	-[b]	
Professional, scientific and technical activities	High/Probably high	0.99 (0.96 to 1.00)	1 entry from 1 study, 1 country	0.01 (-0.00 to 0.02)	1 entry from 1 study, 1 country	NA
	Low/Probably low	-[b]	-[b]	-[b]	-[b]	

[a] P value for test of subgroup differences is shown for level estimates only as it was not possible to generate this for the subgroup analyses for prevalence.
[b] No data available.

of evidence were judged to be of moderate quality of evidence; for example, for occupational exposure to silica in Mining we judged the body of evidence for prevalence to be of moderate quality of evidence. Additionally, the bodies of evidence for prevalence of occupational exposure to silica in Construction and Manufacturing were also judged to be of moderate quality of evidence; and the body of evidence for prevalence of exposure to coal dust in Mining (coal and lignite) was judged to have moderate quality of evidence. We consider these suitable as input data for WHO/ILO modelling of work-related burden of disease and injury. Furthermore, other selected estimates of the prevalences and levels of occupational exposure to asbestos and coal dust may perhaps also be suitable for estimation purposes (with limitations acknowledged).

7. Conclusions

Our systematic review and *meta*-analysis concluded that the quality of the bodies of evidence for prevalences and levels of occupational exposure to silica, asbestos and coal dust vary by industrial sector. For silica, while some bodies of evidence (i.e. prevalence of exposure in Construction, Manufacturing and Mining) were of moderate quality of evidence, others were of low or very low quality of evidence. The bodies of evidence for asbestos were judged to be of low or very low quality of evidence. For coal dust, the bodies of evidence were judged to be of

Table 25
Sensitivity *meta*-analysis, prevalence and level of occupational exposure to asbestos by industrial sector by risk of bias rating for selection of participants into the studies.

Industrial sector	Risk of bias for selection of participants into the studies	Prevalence (95% confidence interval)	Numbers of measures (entries) of prevalence of exposure, studies, and countries, and I^2	Level f/ml (95% confidence interval)	Numbers of measures (entries) of level of exposure, studies, and countries, and I^2	P value for test of subgroup differences for level [a]
Construction	High/Probably high	1.00 (0.95 to 1.00)	1 entry from 1 study	0.11 (0.03 to 0.18)	3 entries from 2 studies, I^2 95%	P = 0.02
	Low/Probably low	0.73 (0.59 to 0.84)	9 entries from 6 studies, I^2 100%	0.01 (0.01 to 0.02)	12 entries from 4 studies, I^2 100%	
Manufacturing	High/Probably high	0.98 (0.95 to 1.00)	6 entries from 6 studies, I^2 79%	0.16 (0.10, 0.21)	10 entries from 5 studies, I^2 97%	NA
	Low/Probably low	1.00 (0.95 to 1.00)	1 entry from 1 study	-[b]	-[b]	
Other mining and quarrying	High/Probably high	0.85 (0.77 to 0.91)	1 entry from 1 study	0.01 (0.01 to 0.02)	1 entry from 1 study	NA
	Low/Probably low	-[b]	-[b]	-[b]	-[b]	
Electricity, gas, steam and air conditioning supply	High/Probably high	0.98 (0.91 to 1.00)	1 entry from 1 study	0.40 (0.21 to 0.58)	1 entry from 1 study	NA
	Low/Probably low	0.20 (0.11 to 0.31)	1 entry from 1 study	-[b]	-[b]	
Water supply, sewerage, waste management and remediation	High/Probably high	-[b]	-[b]	-[b]	-[b]	NA
	Low/Probably low	-[b]	-[b]	0.00 (0.00 to 0.00)	1 entry from 1 study, 1 country	

[a] P value for test of subgroup differences is shown for level estimates only as it was not possible to generate this for the subgroup analyses for prevalence.
[b] No data available.

Table 26
Sensitivity *meta*-analysis, prevalence and level of occupational exposure to coal dust by industrial sector by risk of bias rating for selection of participants into the studies.

Industrial sector	Risk of bias rating for selection of participants into the studies	Prevalence (95% confidence interval)	Numbers of measures (entries) of prevalence of exposure, studies, and countries, and I^2	Level f/ml (95% confidence interval)	Numbers of measures (entries) of level of exposure, studies, and countries, and I^2	P value for test of subgroup differences for level [a]
Mining of coal and lignite	High/Probably high	0.99 (0.99 to 1.00)	4 entries from 4 studies, I^2 0%	0.77 (0.68, 0.86)	5 entries from 3 studies	NA
	Low/Probably low	1.00 (1.00 to 1.00)	2 entries from 2 studies, I^2 0%	-[b]	-[b]	
Electricity, gas, steam and air conditioning supply	High/Probably high	-[b]	-[b]	-[b]	-[b]	NA
	Low/Probably low	0.02 (0.00 to 0.04)	1 entry from 1 study	0.60 (-6.95 to 8.14)	1 entry from 1 study	

[a] P value for test of subgroup differences is shown for level estimates only as it was not possible to generate this for the subgroup analyses for prevalence.
[b] No data available.

either moderate quality of evidence (i.e., prevalence in Mining of coal and lignite), low quality of evidence or very low quality of evidence.

Selected estimates of the prevalences and levels of occupational exposure to silica are considered suitable as input data for the WHO/ILO Joint Estimates, and selected estimates of the prevalences and levels of occupational exposure to asbestos and coal dust may perhaps also be suitable for estimation purposes.

8. Differences between protocol and systematic review

- In our protocol (Mandrioli et al. 2018), we intended to use a modified version of theNavigation Guide risk of bias tool, but then WHO and ILO developed a specific tool for assessing risk of bias in studies estimating prevalence and level of exposure to occupational risk factors (RoB-SPEO (Pega et al. 2020a)), and WHO validated the tool working with individual experts (Momen et al. 2022). We applied this dedicated tool in this systematic review.
- We intended in the protocol to use a modified version of the Navigation Guide approach for assessing quality of evidence. WHO subsequently developed a specific approach for assessing quality of evidence in occupational exposure prevalence and level studies (QoE-SPEO (Pega et al. 2022b)). This approach was applied in the systematic review.
- We intended to review only the prevalence of any occupational exposure to dusts and/or fibres. However, at the review stage, we also included as additional eligible exposures the level of exposure to silica, asbestos and coal dust. The reason was that WHO and ILO started considering building a cumulative exposure model for the WHO/ILO Joint Estimates, which required data on both prevalences and levels of exposures to dusts and/or fibres.
- We intended to produce one pooled estimate of prevalence of occupational exposure for each of silica, asbestos and coal dust, however, it became apparent that a large number of studies were subject to selection bias. Prevalence estimates from the bodies of evidence

Table 27
Ratings from QoE-SPEO for prevalence and level of occupational exposure to silica.

Industrial sector	Type	Rating of expected heterogeneity (QoE-SPEO Step 1; (Pega et al. 2022b))	Number of downgrades and reasons for downgrading (if any) (QoE-SPEO Step 2)	Final quality of evidence rating (QoE-SPEO Step 3)
Construction	Prevalence	High	Total downgrade of −1 −1 for serious concerns about indirectness	Moderate quality of evidence
	Level	High	Total downgrade of −3 −1 for serious concerns about risk of bias −1 for serious concerns about indirectness −1 for serious concerns about imprecision	Very low quality of evidence
Manufacturing	Prevalence	High	Total downgrade of −1 −1 for serious concerns about indirectness	Moderate quality of evidence
	Level	High	Total downgrade of −3 −1 for serious concerns about risk of bias −1 for serious concerns about indirectness −1 for serious concerns about imprecision	Very low quality of evidence
Mining	Prevalence	High	Total downgrade of −1 −1 for serious concerns about indirectness	Moderate quality of evidence
	Level	High	Total downgrade of −2 −1 for serious concerns about indirectness −1 for serious concerns about imprecision	Low quality of evidence
Crop and animal production	Prevalence	High	Total downgrade of −3 −1 for serious concerns about risk of bias −2 for very serious concerns about indirectness	Very low quality of evidence
	Level	High	Total downgrade of −4 −2 for serious concerns about risk of bias −2 for very serious concerns about indirectness	Very low quality of evidence
Electricity, gas, steam and air conditioning supply	Prevalence	Medium	Total downgrade of −3 −1 for serious concerns about risk of bias −2 for very serious concerns about indirectness	Very low quality of evidence
	Level	High	Total downgrade of −3 −1 for serious concerns about risk of bias −2 for very serious concerns about indirectness	Very low quality of evidence
Professional, scientific and technical activities	Prevalence	High	Total downgrade of −5 −1 for serious concerns about risk of bias −2 for very serious concerns about indirectness −1 for serious concerns about inconsistency −1 for serious concerns about imprecision	Very low quality of evidence
	Level	High	Total downgrade of −5 −1 for serious concerns about risk of bias −2 for very serious concerns about indirectness −2 for very serious concerns about imprecision	Very low quality of evidence

could not be applied to all workers. Therefore, occupational exposure to silica, asbestos and coal dust were pooled within industrial sectors only (and not across all industrial sectors as originally planned).

- We intended to include studies reporting exposure data disaggregated by country, sex, age group, industrial sector and occupation, but due to limited data on sex and age group we were only able to include studies with data disaggregated by country and industrial sector.
- We intended to use Rayyan Systematic Reviews Web App or DistillerSR for study selection but used Covidence instead.
- We planned to use the computer software Stata to carry out the *meta*-analyses for both occupational exposure prevalence and level. However, for prevalence *meta*-analyses we used MetaXL. Additionally, double arcsine transformation was used to provide confidence limits within the floor and ceiling (0–100%). The levels *meta*-analyses were entered into RevMan.
- We planned to generate funnel plots for all *meta*-analyses, however as these have been shown to provide erroneous results when pooling proportions (Hunter et al. 2014) we generated Doi plots with LFK statistics to assess publication bias (Cheema et al. 2022).
- We planned to update the PubMed search performed up to 30 April 2018, but for pragmatic reasons in order to finalise the systematic review we did not perform an updated search, and the last searches in all databases were performed between April and June 2018.

Table 28
Ratings from QoE-SPEO for prevalence and level of occupational exposure to asbestos.

Industrial sector	Type	Rating of expected heterogeneity (QoE-SPEO Step 1; (Pega et al. 2022b))	Number of downgrades and reasons for downgrading (if any) (QoE-SPEO Step 2)	Final quality of evidence rating (QoE-SPEO Step 3)
Construction	Prevalence	High	Total downgrade of −2 −2 for very serious concerns about indirectness	Low quality of evidence
	Level	High	Total downgrade of −4 −2 for very serious concerns about indirectness −2 for very serious concerns about imprecision	Very low quality of evidence
Manufacturing	Prevalence	High	Total downgrade of −4 −1 for serious concerns about risk of bias −2 for serious concerns about indirectness −1 for serious concerns about imprecision	Very low quality of evidence
	Level	High	Total downgrade of −4 −2 for serious concerns about risk of bias −2 for serious concerns about indirectness	Very low quality of evidence
Other mining and quarrying	Prevalence	High	Total downgrade of −4 −2 for very serious concerns about risk of bias −2 for very serious concerns about indirectness	Very low quality of evidence
	Level	High	Total downgrade of −6 −2 for very serious concerns about risk of bias −2 for very serious concerns about indirectness −1 for serious concerns about inconsistency −1 for serious concerns about imprecision	Very low quality of evidence
Electricity, gas, steam and air conditioning supply	Prevalence	High	Total downgrade of −3 −1 for serious concerns about risk of bias −2 for very serious concerns about indirectness	Very low quality of evidence
	Level	High	Total downgrade of −3 −1 for serious concerns about risk of bias −2 for very serious concerns about indirectness	Very low quality of evidence
Water supply, sewerage, waste management and remediation	Prevalence	NA	NA	NA
	Level	High	Total downgrade of −6 −2 for very serious concerns about indirectness −2 for very serious concerns about inconsistency −2 for very serious concerns about imprecision	Very low quality of evidence

- We did not originally plan to conduct sensitivity analyses, but in the systematic review did conduct one sensitivity analysis for each exposure. We compared studies we judged as at high or probably high risk of bias in bias due to selection into the study with studies judged as at low or probably low risk of this bias. The rationale was that our primary concerns for risk of bias was in this domain, and we wanted to check for differences in included studies by level of risk of bias to inform our quality of evidence assessments.

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10. Sponsors

The sponsors of this systematic review are WHO and the ILO.

Table 29
Ratings from QoE-SPEO for prevalence and level of occupational exposure to coal dust.

Industrial sector	Type	Rating of expected heterogeneity (QoE-SPEO Step 1; Pega et al. 2022b)	Number of downgrades and reasons for downgrading (if any) (QoE-SPEO Step 2)	Final quality of evidence rating (QoE-SPEO Step 3)
Mining of coal and lignite	Prevalence	Low	Total downgrade of −1 −1 for serious concerns about risk of bias	Moderate quality of evidence
	Level	High	Total downgrade of −2 −1 for serious concerns about risk of bias −1 for serious concerns about indirectness	Low quality of evidence
Electricity, gas, steam and air conditioning supply	Prevalence	High	Total downgrade of −4 −2 for very serious concerns about indirectness −1 for serious concerns about inconsistency −1 for serious concerns about imprecision	Very low quality of evidence
	Level	High	Total downgrade of −2 −2 for very serious concerns about indirectness	Low quality of evidence

Table 30
Summary of evidence for prevalence and level of occupational exposure to silica.

Prevalence and level of occupational exposure to silica among workers

Population: Any manual workers
Settings: All countries and work settings
Exposure: Occupational exposure to silica

Industrial sector	Prevalence			Level		
	Prevalence estimate (95% CI)	No. of measurements (studies)	QoE-SPEO quality of evidence rating [a,b]	Level estimate mg/m^3 (95% CI)	No. of measurements (studies)	QoE-SPEO quality of evidence rating [a,b]
Construction	**0.89** (0.84 to 0.93)	2479 measurements (24 entries from 17 studies)	⊕⊕⊕⊖ Moderate quality of evidence	- [c]	2352 measurements (25 entries from 16 studies)	⊕⊖⊖⊖ Very low quality of evidence
Manufacturing	**0.85** (0.78 to 0.91)	40,073 measurements (39 entries from 24 studies)	⊕⊕⊕⊖ Moderate quality of evidence	- [c]	7733 measurements (30 entries from 14 studies)	⊕⊖⊖⊖ Very low quality of evidence
Mining	**0.75** (0.68 to 0.82)	222,276 measurements (29 entries from 20 studies)	⊕⊕⊕⊖ Moderate quality of evidence	**0.04** (0.03 to 0.05)	2,349,598 measurements (43 entries from 17 studies)	⊕⊕⊖⊖ Low quality of evidence
Crop and animal production	- [c]	479 measurements (3 entries from 3 studies)	⊕⊖⊖⊖ Very low quality of evidence	- [c]	335 measurements (2 entries from 2 studies)	⊕⊖⊖⊖ Very low quality of evidence
Electricity, gas, steam and air conditioning supply	- [c]	136 measurements (2 entries from 2 studies)	⊕⊖⊖⊖ Very low quality of evidence	- [c]	28 measurements (1 entry from 1 study)	⊕⊖⊖⊖ Very low quality of evidence
Professional, scientific and technical activities	- [c]	41 measurements (1 entry from 1 study)	⊕⊖⊖⊖ Very low quality of evidence	- [c]	18,313 measurements (3 entries from 2 studies)	⊕⊖⊖⊖ Very low quality of evidence

[a] QoE-SPEO quality of evidence ratings (Pega et al. 2022b):
[a]*High quality of evidence*: Further research is very unlikely to change our confidence in the estimate of prevalence.
Moderate quality of evidence: Further research is likely to have an important impact on our confidence in the estimate of prevalence and may change the estimate.
Low quality of evidence: Further research is very likely to have an important impact on our confidence in the estimate of prevalence and is likely to change the estimate.
Very low quality of evidence: We are very uncertain about the estimate.
[b] See Table 27 and Appendix 15 for details of downgrading.
[c] Pooled estimate not shown due to very low quality of evidence.

Author contributions

Had the idea for the systematic review: FP, Ivan Ivanov (WHO), Nancy Leppink (ILO).

Coordinated the entire series of systematic reviews: FP, YU.

Selected the lead reviewers and gathered the review teams: FP, Ivan Ivanov, Nancy Leppink.

Were the lead reviewers of this systematic review: VS, DM, PTJS.

Led the design of the systematic review including developed the standard methods: FP.

Contributed substantially to the design of the systematic review: VS, DM, NCM, DS, SvdM, PTJS.

Conducted the search: VS, DM, PTJS.

Selected studies: VS, DM, DS, SvdM, PTJS.

Extracted data: VS, DM, BA, WC, WK, JL, SM-R, FM, MP, NR, DS, SS, XS, RS, PT, SvdM, KV.

Requested missing data: VS.

Assessed risk of bias: VS, DM, BA, WC, RAC, LG, TG, BN, WK, JL, SM-R, FM, NR, DS, SS, XS, RS, PT, SvdM, KV, MY.

Conducted the meta-analyses: VS, FP, NCM, DS.

Table 31
Summary of evidence for prevalence and level of occupational exposure to asbestos.

Prevalence and level of occupational exposure to asbestos among workers

Population: Any manual workers
Settings: All countries and work settings
Exposure: Occupational exposure to asbestos

Industrial sector	Prevalence			Level		
	Prevalence estimate (95% CI)	No. of measurements (studies)	QoE-SPEO quality of evidence rating [a,b]	Level estimate f/cm³ (95% CI)	No. of measurements (studies)	QoE-SPEO quality of evidence rating [a,b]
Construction	**0.77** (0.65 to 0.87)	16,580 measurements (9 entries from 6 studies)	⊕⊕⊖⊖ Low quality of evidence	- [c]	12,240 measurements (15 entries from 6 studies)	⊕⊖⊖⊖ Very low quality of evidence
Manufacturing	- [c]	1225 measurements (7 entries from 7 studies)	⊕⊖⊖⊖ Very low quality of evidence	- [c]	1431 measurements (10 entries from 5 studies)	⊕⊖⊖⊖ Very low quality of evidence
Mining (other mining and quarrying)	- [c]	89 measurements (1 entry from 1 study)	⊕⊖⊖⊖ Very low quality of evidence	- [c]	89 measurements (1 entry from 1 study)	⊕⊖⊖⊖ Very low quality of evidence
Electricity, gas, steam and air conditioning supply	- [c]	108 measurements (2 entries from 2 studies)	⊕⊖⊖⊖ Very low quality of evidence	- [c]	46 measurements (1 entry from 1 study)	⊕⊖⊖⊖ Very low quality of evidence
Water supply; sewerage, waste management and remediation	–	0 measurements (0 entries from 0 studies)	–	- [c]	4507 measurements (1 entry from 1 study)	⊕⊖⊖⊖ Very low quality of evidence

[a] QoE-SPEO quality of evidence ratings (Pega et al. 2022b): *High quality of evidence*: Further research is very unlikely to change our confidence in the estimate of prevalence. *Moderate quality of evidence*: Further research is likely to have an important impact on our confidence in the estimate of prevalence and may change the estimate. *Low quality of evidence*: Further research is very likely to have an important impact on our confidence in the estimate of prevalence and is likely to change the estimate. *Very low quality of evidence*: We are very uncertain about the estimate.
[b] See Table 28 and Appendix 16 for details of downgrading.
[c] Pooled estimate not shown due to very low quality of evidence.

Table 32
Summary of evidence for prevalence and level of occupational exposure to coal dust.

Prevalence and level of occupational exposure to coal dust among workers

Population: Any manual workers
Settings: All countries and work settings
Exposure: Occupational exposure to coal dust

Industrial sector	Prevalence			Level		
	Prevalence estimate (95% CI)	No. of measurements (studies)	QoE-SPEO quality of evidence rating [a,b]	Level estimate mg/m³ (95% CI)	No. of measurements (studies)	QoE-SPEO quality of evidence rating [a,b]
Mining (Coal and lignite)	**1.00** (1.00 to 1.00)	3,309 measurements (6 entries from 6 studies)	⊕⊕⊕⊖ Moderate quality of evidence	**0.77** (0.68 to 0.86)	100,092 measurements (5 entries from 3 studies)	⊕⊕⊖⊖ Low quality of evidence
Electricity, gas, steam and air conditioning supply	- [c]	203 measurements (1 entry from 1 study)	⊕⊖⊖⊖ Very low quality of evidence	**0.60** (-6.95 to 8.14)	4 measurements (1 entry from 1 study)	⊕⊕⊖⊖ Low quality of evidence

[a] QoE-SPEO quality of evidence ratings (Pega et al. 2022b): *High quality of evidence*: Further research is very unlikely to change our confidence in the estimate of prevalence. *Moderate quality of evidence*: Further research is likely to have an important impact on our confidence in the estimate of prevalence and may change the estimate. *Low quality of evidence*: Further research is very likely to have an important impact on our confidence in the estimate of prevalence and is likely to change the estimate. *Very low quality of evidence*: We are very uncertain about the estimate.
[b] See Table 29 and Appendix 17 for details of downgrading.
[c] Pooled estimate not shown due to very low quality of evidence.

Assessed quality of evidence: VS, DM, BA, WC, LG, KH, WK, JL, FM, BN, NR, SM-R, DS, RS, SvdM, KV, MZ, PTJS.

Facilitated the quality of evidence assessments: FP, NCM.

Developed the standards and wrote the template for all systematic reviews in the series: FP.

Wrote the first draft of the manuscript using the template: VS, FP.

Revised the manuscript critically for important intellectual content: All authors.

Ensured tailoring of the systematic review for WHO/ILO estimation purposes: FP, NCM.

Ensured harmonization across systematic reviews in the series: FP, NCM.

Approved the final version of the systematic review to be published: All authors.

Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: All authors.

CRediT authorship contribution statement

Vivi Schlünssen: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Software, Writing – original draft, Writing – review & editing. **Daniele Mandrioli:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Frank Pega:** Conceptualization, Data curation, Formal analysis, Investigation, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Natalie C. Momen:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing. **Balázs Ádám:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Weihong Chen:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Robert A. Cohen:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Lode Godderis:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Thomas Göen:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Kishor Hadkhale:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Watinee Kunpuek:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Jianlin Lou:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Stefan Mandic-Rajcevic:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Federica Masci:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Ben Nemery:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Madalina Popa:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Natthadanai Rajatanavin:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Daria Sgargi:** Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing. **Somkiat Siriruttanapruk:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Xin Sun:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Repeepong Suphanchaimat:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Panithee Thammawijaya:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Yuka Ujita:** Conceptualization, Project administration, Supervision, Investigation, Validation, Writing – review & editing. **Stevie van der Mierden:** Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. **Katya Vangelova:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Meng Ye:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Muzimkhulu Zungu:** Data curation, Formal analysis, Investigation, Validation, Writing – review & editing. **Paul T.J. Scheepers:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Professor Vivi Schlünssen was the Chair of the Danish Quality Committee for Occupational Exposure Limits of the Danish Working Environment Authority from the year 2016, up until 30 June 2022. The other authors declare no conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2023.107980.

References

104th International Labour Conference. Transition from the informal to the formal economy (Recommendation No. 204). Available from: https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:R204, accessed 17 June 2021.; 2015.

Akaoka, K., McKendry, I., Saxton, J., Cottle, P.W., 2017. Impact of coal-carrying trains on particulate matter concentrations in South Delta, British Columbia, Canada. Environ. Pollut. 223, 376–383.

Andersson, L., Bryngelsson, I.L., Ohlson, C.G., Nayström, P., Lilja, B.G., Westberg, H., 2009. Quartz and dust exposure in Swedish iron foundries. J. Occup. Environ. Hyg. 6, 9–18.

Andersson, L., Burdorf, A., Bryngelsson, I.L., Westberg, H., 2012. Estimating trends in quartz exposure in Swedish iron foundries–predicting past and present exposures. Ann. Occup. Hyg. 56, 362–372.

Ansari, F.A., Ahmad, I., Ashquin, M., Yunus, M., Rahman, Q., 2007. Monitoring and identification of airborne asbestos in unorganized sectors, India. Chemosphere 68, 716–723.

Archer, J.D., Cooper, G.S., Reist, P.C., Storm, J.F., Nylander-French, L.A., 2002. Exposure to respirable crystalline silica in eastern North Carolina farm workers. AIHA J (Fairfax, Va) 63, 750–755.

Azari, M.R.R., M., Salehpour, S., Mehrabi, Y., Jafari, M.J., Moaddeli, A.N., Movahedi, M., Ramezankhani, A., Hatami, H., Mosavion, M.A., Ramazani, B., 2009. Risk Assessment of Workers Exposed to Crystalline Silica Aerosols in the East Zone of Tehran. Tanaffos 8, 43-50.

Bakke, B., Stewart, P., Ulvestad, B., Eduard, W., 2001. Dust and gas exposure in tunnel construction work. Aihaj 62, 457–465.

Bakke, B., Ulvestad, B., Thomassen, Y., Woldbaek, T., Ellingsen, D.G., 2014. Characterization of occupational exposure to air contaminants in modern tunnelling operations. Ann. Occup. Hyg. 58, 818–829.

Barendregt, J.J., Doi, S.A., Lee, Y.Y., Norman, R.E., Vos, T., 2013. Meta-analysis of prevalence. J. Epidemiol. Community Health 67, 974–978.

Beer, C., Kolstad, H.A., Sondergaard, K., Bendstrup, E., Heederik, D., Olsen, K.E., Omland, O., Petsonk, E., Sigsgaard, T., Sherson, D.L., Schlunssen, V., 2017. A systematic review of occupational exposure to coal dust and the risk of interstitial lung diseases. Eur Clin Respir J 4, 1264711.

Beller, E.M., Glasziou, P.P., Altman, D.G., Hopewell, S., Bastian, H., Chalmers, I., Gotzsche, P.C., Lasserson, T., Tovey, D., 2013. Prisma for Abstracts Group. PRISMA for Abstracts: reporting systematic reviews in journal and conference abstracts. PLoS Med. 10, e1001419.

Bird, M.J., MacIntosh, D.L., Williams, P.L., 2004. Occupational exposures during routine activities in coal-fueled power plants. J. Occup. Environ. Hyg. 1, 403–413.

Blanco-Romero, L.E., Vega, L.E., Lozano-Chavarria, L.M., Partanen, T.J., 2011. CAREX Nicaragua and Panama: Worker exposures to carcinogenic substances and pesticides. Int. J. Occup. Environ. Health 17, 251–257.
Borton, E.K., Lemasters, G.K., Hilbert, T.J., Lockey, J.E., Dunning, K.K., Rice, C.H., 2012. Exposure estimates for workers in a facility expanding Libby vermiculite: updated values and comparison with original 1980 values. J. Occup. Environ. Med. 54, 1350–1358.
Carneiro, A.P., Braz, N.F., Algranti, E., Bezerra, O.M., Araujo, N.P., Amaral Eng Hyg, L.S., Edmé, J.L., Sobaszek, A., Chérot-Kornobis, N., 2017. Silica exposure and disease in semi-precious stone craftsmen, Minas Gerais, Brazil. Am. J. Ind. Med. 60, 239-247.
Cattaneo, A., Somigliana, A., Gemmi, M., Bernabeo, F., Savoca, D., Cavallo, D.M., Bertazzi, P.A., 2012. Airborne concentrations of chrysotile asbestos in serpentine quarries and stone processing facilities in Valmalenco, Italy. Ann Occup Hyg 56, 671–683.
Cheema, H.A., Shahid, A., Ehsan, M., Ayyan, M., 2022. The misuse of funnel plots in meta-analyses of proportions: are they really useful? Clin. Kidney J. 15, 1209–1210.
Chen, J.L., Su, L.F., Tsai, C.L., Liu, H.H., Lin, M.H., Tsai, P.J., 2007. Mass, number and surface area concentrations of alpha-quartz exposures of refractory material manufacturing workers. J. Occup. Health 49, 411–417.
Chen, W., Liu, Y., Wang, H., Hnizdo, E., Sun, Y., Su, L., Zhang, X., Weng, S., Bochmann, F., Hearl, F.J., Chen, J., Wu, T., 2012. Long-term exposure to silica dust and risk of total and cause-specific mortality in Chinese workers: a cohort study. PLoS Med. 9, e1001206.
Chess, L.E., Gagnier, J.J., 2016. Applicable or non-applicable: investigations of clinical heterogeneity in systematic reviews. BMC Med. Res. Method. 16, 19.
Churchyard, G.J., Ehrlich, R., teWaterNaude, J.M., Pemba, L., Dekker, K., Vermeijs, M., White, N., Myers, J., 2004. Silicosis prevalence and exposure-response relations in South African goldminers. Occup. Environ. Med. 61, 811–816.
Damiran, N., Silbergeld, E.K., Frank, A.L., Lkhasuren, O., Ochir, C., Breysse, P.N., 2015. Exposure to airborne asbestos in thermal power plants in Mongolia. Int. J. Occup. Environ. Health 21, 137–141.
De Berardis, B., Incocciati, E., Massera, S., Gargaro, G., Paoletti, L., 2007. Airborne silica levels in an urban area. Sci. Total Environ. 382, 251–258.
Deeks, J., Higgins, J., Altman, D., 2011. Chapter 9: Analysing data and undertaking meta-analyses. In: Higgins, J., Green, S., (Eds.), Cochrane Handbook for Systematic Reviews of Interventions Version 510: The Cochrane Collaboration; 2011 Available from https://trainingcochraneorg/handbook/archive/v51/, accessed 17 June 2021; 2011.
Descatha, A., Sembajwe, G., Baer, M., Boccuni, F., Di Tecco, C., Duret, C., Evanoff, B.A., Gagliardi, D., Ivanov, I.D., Leppink, N., Marinaccio, A., Magnusson Hanson, L.L., Ozguler, A., Pega, F., Pell, J., Pico, F., Prüss-Üstün, A., Ronchetti, M., Roquelaure, Y., Sabbath, E., Stevens, G.A., Tsutsumi, A., Ujita, Y., Iavicoli, S., 2018. WHO/ILO work-related burden of disease and injury: protocol for systematic reviews of exposure to long working hours and of the effect of exposure to long working hours on stroke. Environ. Int. 119, 366–378.
Descatha, A., Sembajwe, G., Pega, F., Ujita, Y., Baer, M., Boccuni, F., Di Tecco, C., Duret, C., Evanoff, B.A., Gagliardi, D., Godderis, L., Kang, S.K., Kim, B.J., Li, J., Magnusson Hanson, L.L., Marinaccio, A., Ozguler, A., Pachito, D., Pell, J., Pico, F., Ronchetti, M., Roquelaure, Y., Rugulies, R., Schouteden, M., Siegrist, J., Tsutsumi, A., Iavicoli, S., 2020. The effect of exposure to long working hours on stroke: a systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 142, 105746.
Dion, C., Dufresne, A., Jacob, M., Perrault, G., 2005. Assessment of exposure to quartz, cristobalite and silicon carbide fibres (whiskers) in a silicon carbide plant. Ann. Occup. Hyg. 49, 335–343.
Drazen, J.M., Van der Weyden, M.B., Sahni, P., Rosenberg, J., Marusic, A., Laine, C., Kotzin, S., Horton, R., Hebert, P.C., Haug, C., Godlee, F., Frizelle, F.A., de Leeuw, P. W., DeAngelis, C.D., 2010a. Uniform format for disclosure of competing interests in ICMJE journals. J. Am. Med. Assoc. 303, 75–76.
Drazen, J.M., de Leeuw, P.W., Laine, C., Mulrow, C., DeAngelis, C.D., Frizelle, F.A., Godlee, F., Haug, C., Hebert, P.C., James, A., Kotzin, S., Marusic, A., Reyes, H., Rosenberg, J., Sahni, P., Van der Weyden, M.B., Zhaori, G., 2010b. Toward more uniform conflict disclosures: the updated ICMJE conflict of interest reporting form. J. Am. Med. Assoc. 304, 212–213.
ES21 Federal Working Group on Exposure Science. Glossary of Exposure Science Terms, 2015.
Estellita, L.D.S.A., Anjos, R.M.D., Yoshimura, E.M., Velasco, H., Da Silva, A., Aguiar, J., 2010. Analysis and risk estimates to workers of Brazilian granitic industries and sandblasters exposed to respirable crystalline silica and natural radionuclides. Radiat. Measure. 45, 196-203.
Fevotte, J., Dananche, B., Delabre, L., Ducamp, S., Garras, L., Houot, M., Luce, D., Orlowski, E., Pilorget, C., Lacourt, A., Brochard, P., Goldberg, M., Imbernon, E., 2011. Matgene: a program to develop job-exposure matrices in the general population in France. Ann. Occup. Hyg. 55, 865–878.
Flanagan, M.E., Seixas, N., Becker, P., Takacs, B., Camp, J., 2006. Silica exposure on construction sites: results of an exposure monitoring data compilation project. J. Occup. Environ. Hyg. 3, 144–152.
Føreland, S., Bye, E., Bakke, B., Eduard, W., 2008. Exposure to fibres, crystalline silica, silicon carbide and sulphur dioxide in the norwegian silicon carbide industry. Ann. Occup. Hyg. 52, 317–336.
Forsyth, S.R., Odierna, D.H., Krauth, D., Bero, L.A., 2014. Conflicts of interest and critiques of the use of systematic reviews in policymaking: an analysis of opinion articles. Syst. Rev. 3, 122.
Fulekar, M.H., 1999. Occupational exposure to dust in quartz manufacturing industry. Ann. Occup. Hyg. 43, 269–273.
Furuya-Kanamori, L., Barendregt, J.J., Doi, S.A.R., 2018. A new improved graphical and quantitative method for detecting bias in meta-analysis. Int. J. Evid. Based Healthc. 16, 195–203.
G. B. D. Risk Factors Collaborators, 2017. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet 390, 1345-1422.
Galea, K.S., Mair, C., Alexander, C., de Vocht, F., van Tongeren, M., 2016. Occupational Exposure to Respirable Dust, Respirable Crystalline Silica and Diesel Engine Exhaust Emissions in the London Tunnelling Environment. Ann. Occup. Hyg. 60, 263–269.
Garcia, A.M., Gonzalez-Galarzo, M.C., Kauppinen, T., Delclos, G.L., Benavides, F.G., 2013. A job-exposure matrix for research and surveillance of occupational health and safety in Spanish workers: MatEmESp. Am. J. Ind. Med. 56, 1226–1238.
Godderis, L., Boonen, E., Cabrera Martimbianco, A.L., Delvaux, E., Ivanov, I.D., Lambrechts, M.C., Latorraca, C.O.C., Leppink, N., Pega, F., Pruss-Ustun, A.M., Riera, R., Ujita, Y., Pachito, D.V., 2018. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of exposure to long working hours and of the effect of exposure to long working hours on alcohol consumption and alcohol use disorders. Environ. Int. 120, 22–33.
Golbabaei, F., Barghi, M.A., Sakhaei, M., 2004. Evaluation of workers' exposure to total, respirable and silica dust and the related health symptoms in Senjedak stone quarry, Iran. Ind Health 42, 29–33.
Gottesfeld, P., Andrew, D., Dalhoff, J., 2015. Silica Exposures in Artisanal Small-Scale Gold Mining in Tanzania and Implications for Tuberculosis Prevention. J. Occup. Environ. Hyg. 12, 647–653.
Green, D.A., McAlpine, G., Semple, S., Cowie, H., Seaton, A., 2008. Mineral dust exposure in young Indian adults: an effect on lung growth? Occup. Environ. Med. 65, 306–310.
Grové, T., Van Dyk, T., Franken, A., Du Plessis, J., 2014. The evaluation and quantification of respirable coal and silica dust concentrations: a task-based approach. J. Occup. Environ. Hyg. 11, 406–414.
Guénel, P., Breum, N.O., Lynge, E., 1989. Exposure to silica dust in the Danish stone industry. Scand. J. Work Environ. Health 15, 147–153.
Hammond, D.R., Shulman, S.A., Echt, A.S., 2016. Respirable crystalline silica exposures during asphalt pavement milling at eleven highway construction sites. J. Occup. Environ. Hyg. 13, 538–548.
Hayumbu, P., Robins, T.G., Key-Schwartz, R., 2008. Cross-sectional silica exposure measurements at two Zambian copper mines of Nkana and Mufulira. Int. J. Environ. Res. Public Health 5, 86–90.
Healy, C.B., Coggins, M.A., Van Tongeren, M., MacCalman, L., McGowan, P., 2014. Determinants of respirable crystalline silica exposure among stoneworkers involved in stone restoration work. Ann. Occup. Hyg. 58, 6–18.
Heederik, D., Attfield, M., 2000. Characterization of dust exposure for the study of chronic occupational lung disease: a comparison of different exposure assessment strategies. Am. J. Epidemiol. 151, 982–990.
Hicks, J., Yager, J., 2006. Airborne crystalline silica concentrations at coal-fired power plants associated with coal fly ash. J. Occup. Environ. Hyg. 3, 448–455.
Huizer, D., Spee, T., Lumens, M., Kromhout, H., 2010. Exposure to respirable dust and crystalline silica in bricklaying education at Dutch vocational training centers. Am. J. Ind. Med. 53, 628–634.
Hulshof, C.T.J., Colosio, C., Daams, J.G., Ivanov, I.D., KC, P., Kuijer, P.P.F.M., Leppink, N., Mandic-Rajcevic, S., Masci, F., van der Molen, H.F., Neupane, S., Nygard, C.H., Oakman, J., Pega, F., Proper, K., Pruss-Ustun, A.M., Ujita, Y., Frings-Dresen, M.H.W., 2019. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of exposure to occupational ergonomic risk factors and of the effect of exposure to occupational ergonomic risk factors on osteoarthritis of hip or knee and selected other musculoskeletal diseases. Environ. Int. 125, 554–566.
Hulshof, C.T.J., Pega, F., Neupane, S., van der Molen, H.F., Colosio, C., Daams, J.G., Descatha, A., KC, P., Kuijer, P.P.F.M., Mandic-Rajcevic, S., Masci, F., Morgan, R.L., Nygard, C.H., Oakman, J., Proper, K.I., Solovieva, S., Frings-Dresen, M.H.W., 2021a. The prevalence of occupational exposure to ergonomic risk factors: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ Int 146, 106157.
Hulshof, C.T.J., Pega, F., Neupane, S., Colosio, C., Daams, J.G., KC, P., Kuijer, P.P.F.M., Mandic-Rajcevic, S., Masci, F., van der Molen, H.F., Nygard, C.H., Oakman, J., Proper, K.I., Frings-Dresen, M.H.W., 2021b. The effect of occupational exposure to ergonomic risk factors on osteoarthritis of hip or knee and selected other musculoskeletal diseases: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ Int 106349.
Hunter, J.P., Saratzis, A., Sutton, A.J., Boucher, R.H., Sayers, R.D., Bown, M.J., 2014. In meta-analyses of proportion studies, funnel plots were found to be an inaccurate method of assessing publication bias. J. Clin. Epidemiol. 67, 897–903.
International Labour Organization, 1988. International standard classification of occupations - (ISCO-88). ILO, Geneva.
International Labour Organization. ISCO-08: International Standard Classification of Occupations, 2012.
International Labour Organization, 2014. Safety and health at work : a vision for sustainable prevention: XX World Congress on Safety and Health at Work 2014: Global Forum for Prevention, 24-27 August 2014, Frankfurt, Germany.
Kakooei, H., Sameti, M., Kakooei, A.A., 2007. Asbestos exposure during routine brake lining manufacture. Ind. Health 45, 787–792.
Kakooei, H., Normohammadi, M., 2014. Asbestos exposure among construction workers during demolition of old houses in Tehran, Iran. Ind Health 52, 71–77.
Kauffer, E., Vincent, R., 2007. Occupational exposure to mineral fibres: analysis of results stored on colchic database. Ann. Occup. Hyg. 51, 131–142.

Kauppinen, T., Toikkanen, J., Pedersen, D., Young, R., Ahrens, W., Boffetta, P., Hansen, J., Kromhout, H., Maqueda Blasco, J., Mirabelli, D., de la Orden-Rivera, V., Pannett, B., Plato, N., Savela, A., Vincent, R., Kogevinas, M., 2000. Occupational exposure to carcinogens in the European Union. Occup. Environ. Med. 57, 10–18.

Kauppinen, T., Uuksulainen, S., Saalo, A., Makinen, I., 2013. Trends of occupational exposure to chemical agents in Finland in 1950–2020. Ann. Occup. Hyg. 57, 593–609.

Khoza, N.G.T., Schutte, P.C., 2012. Worker exposure to silica dust in South African non-mining industries in Gauteng: an exploratory study. Occupational Health Southern Africa 18, 18-26.

Kim, T.S., Kim, H.A., Heo, Y., Park, Y., Park, C.Y., Roh, Y.M., 2002. Level of silica in the respirable dust inhaled by dental technicians with demonstration of respirable symptoms. Ind. Health 40, 260–265.

Koo, J.W.C., Park, C.Y., Lee, S.H., Lee, K.S., Roh, Y.M., Yim, H.W., 2000. The effect of silica dust on ventilatory function of foundry workers. J. Occup. Health 42, 251-257.

Kreiss, K., Zhen, B., 1996. Risk of silicosis in a Colorado mining community. Am. J. Ind. Med. 30, 529–539.

Kromhout, H., Symanski, E., Rappaport, S.M., 1993. A comprehensive evaluation of within- and between-worker components of occupational exposure to chemical agents. Ann. Occup. Hyg. 37, 253–270.

Kullman, G.J., Greife, A.L., Costello, J., Hearl, F.J., 1995. Occupational exposures to fibers and quartz at 19 crushed stone mining and milling operations. Am. J. Ind. Med. 27, 641–660.

Kunpeuk, W., Julchoo, S., Phaiyarom, M., Sosom, J., Sinam, P., Sukaew, T., Rajatanavin, N., Suphanchaimat, R., Thammawijaya, P., Siriruttanapruk, S., 2021. A Scoping Review on Occupational Exposure of Silica and Asbestos among Industrial Workers in Thailand. Outbreak, Surveillance, Investigation Response 14, 41–61.

Lavoué, J., Bégin, D., Beaudry, C., Gérin, M., 2007. Monte Carlo simulation to reconstruct formaldehyde exposure levels from summary parameters reported in the literature. Ann. Occup. Hyg. 51, 161–172.

Lee, Y.K., B., Seok Kwak, H., Young Park, S., Choi, B.-S., 2014. The stone workers exposure to crystalline silica in the construction industry. Europ. Respiratory J. 44.

Li, J., Brisson, C., Clays, E., Ferrario, M.M., Ivanov, I.D., Landsbergis, P., Leppink, N., Pega, F., Pikhart, H., Prüss-Üstün, A., Rugulies, R., Schnall, P.L., Stevens, G., Tsutsumi, A., Ujita, Y., Siegrist, J., 2018. WHO/ILO work-related burden of disease and injury: protocol for systematic reviews of exposure to long working hours and of the effect of exposure to long working hours on ischaemic heart disease. Environ. Int. 119, 558–569.

Li, J., Pega, F., Ujita, Y., Brisson, C., Clays, E., Descatha, A., Ferrario, M.M., Godderis, L., Iavicoli, S., Landsbergis, P.A., Metzendorf, M.I., Morgan, R.L., Pachito, D.V., Pikhart, H., Richter, B., Roncaioli, M., Rugulies, R., Schnall, P.L., Sembajwe, G., Trudel, X., Tsutsumi, A., Woodruff, T.J., Siegrist, J., 2020. The effect of exposure to long working hours on ischaemic heart disease: a systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 142, 105739.

Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow, C., Gotzsche, P.C., Ioannidis, J.P., Clarke, M., Devereaux, P.J., Kleijnen, J., Moher, D., 2009. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 6, e1000100.

Linch, K.D., 2002. Respirable concrete dust–silicosis hazard in the construction industry. Appl. Occup. Environ. Hyg. 17, 209–221.

Loomis, D., Dzhambov, A.M., Momen, N.C., Chartres, N., Descatha, A., Guha, N., Kang, S. K., Modenese, A., Morgan, R.L., Ahn, S., Martinez-Silveira, M.S., Zhang, S., Pega, F., 2022. The effect of occupational exposure to welding fumes on trachea, bronchus and lung cancer: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 170, 107565.

Love, R.G., Miller, B.G., Groat, S.K., Hagen, S., Cowie, H.A., Johnston, P.P., Hutchison, P. A., Soutar, C.A., 1997. Respiratory health effects of opencast coalmining: a cross sectional study of current workers. Occup. Environ. Med. 54, 416–423.

Love, R.G., Waclawski, E.R., Maclaren, W.M., Wetherill, G.Z., Groat, S.K., Porteous, R.H., Soutar, C.A., 1999. Risks of respiratory disease in the heavy clay industry. Occup. Environ. Med. 56, 124–133.

Lu, J.J., S., Tao, J., Hu, J., 2016. Analysis of dust to evaluate the incidence of pneumoconiosis in huainan coal mines. Analy. Lett. 49, 1783-1793.

Maino, A., Gianelle, V., Onida, F., Albiero, S., 1995. Occupational exposure to asbestos in removal and protective treatment of roof coverings. Med. Lav. 86, 546–554.

Mamuya, S.H., Bråtveit, M., Mwaiselage, J., Mashalla, Y.J., Moen, B.E., 2006a. High exposure to respirable dust and quartz in a labour-intensive coal mine in Tanzania. Ann. Occup. Hyg. 50, 197–204.

Mamuya, S.H., Bråtveit, M., Mwaiselage, J., Moen, B.E., 2006b. Variability of exposure and estimation of cumulative exposure in a manually operated coal mine. Ann. Occup. Hyg. 50, 737–745.

Mandrioli, D., Schlunssen, V., Adam, B., Cohen, R.A., Colosio, C., Chen, W., Fischer, A., Godderis, L., Goen, T., Ivanov, I.D., Leppink, N., Mandic-Rajcevic, S., Masci, F., Nemery, B., Pega, F., Pruss-Ustun, A., Sgargi, D., Ujita, Y., van der Mierden, S., Zungu, M., Scheepers, P.T.J., 2018. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of occupational exposure to dusts and/or fibres and of the effect of occupational exposure to dusts and/or fibres on pneumoconiosis. Environ. Int. 119, 174–185.

Marioryad, H., Kakooei, H., Shahtaheri, S.J., Yunesian, M., Azam, K., 2011. Assessment of airborne asbestos exposure at an asbestos cement sheet and pipe factory in Iran. Regul. Toxicol. Pharm. 60, 200–205.

Massaro, T., Baldassarre, A., Pinca, A., Martina, G.L., Fiore, S., Lettino, A., Cassano, F., Musti, M., 2012. Exposure to asbestos in buildings in areas of Basilicata characterized by the presence of rocks containing tremolite. G. Ital. Med. Lav. Ergon. 34, 568–570.

Mlynarek, S., Corn, M., Blake, C., 1996. Asbestos exposure of building maintenance personnel. Regul. Toxicol. Pharm. 23, 213–224.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., Group, P.-P., 2015. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 4, 1.

Momen, N.C., Streicher, K.N., da Silva, D.T.C., Descatha, A., Frings-Dresen, M.H., Gagliardi, D., Godderis, L., Loney, T., Mandrioli, D., Modenese, A., Morgan, R.L., Pachito, D., Scheepers, P.T.J., Sgargi, D., Paulo, M.S., Schlünssen, V., Sembajwe, G., Sørensen, K., Teixeira, L.R., Tenkate, T., Pega, F., 2022. Assessor burden, inter-rater agreement and user experience of the RoB-SPEO tool for assessing risk of bias in studies estimating prevalence of exposure to occupational risk factors: An analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 107005.

Murray, C.J.L., Ezzati, M., Lopez, A.D., Rodgers, A., Vander Hoorn, S., 2004. Comparative Quantification of Health Risks: Conceptual Framework and Methodological Issues. In: Ezzati, M., Lopez, A.D., Rodgers, A., Murray, C.J.L. (Eds.), Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors. World Health Organization, Geneva.

Nafradi, B., Kiiver, H., Neupane, S., Momen, N.C., Streicher, K.N., Pega, F., 2022. Estimating the population exposed to a risk factor over a time window: A microsimulation modelling approach from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. PLoS One 17, e0278507.

Nieuwenhuijsen, M.J., Noderer, K.S., Schenker, M.B., Vallyathan, V., Olenchock, S., 1999. Personal exposure to dust, endotoxin and crystalline silica in California agriculture. Ann. Occup. Hyg. 43, 35–42.

Normohammadi, M., Kakooei, H., Omidi, L., Yari, S., Alimi, R., 2016. Risk Assessment of Exposure to Silica Dust in Building Demolition Sites. Saf. Health Work 7, 251–255.

Omidianidost, A., Ghasemkhani, M., Azari, M.R., Golbabaei, F., 2015. Assessment of Occupational Exposure to Dust and Crystalline Silica in Foundries. Tanaffos 14, 208–212.

Omidianidost, A., Ghasemkhani, M., Kakooei, H., Shahtaheri, S.J., Ghanbari, M., 2016. Risk Assessment of Occupational Exposure to Crystalline Silica in Small Foundries in Pakdasht. Iran. Iran J Public Health 45, 70–75.

Oudyk, J.D., 1995. Review of an extensive ferrous foundry silica sampling program. Appl. Occup. Environ. Hyg. 10, 331–340.

Pachito, D.V., Pega, F., Bakusic, J., Boonen, E., Clays, E., Descatha, A., Delvaux, E., De Bacquer, D., Koskenvuo, K., Kroger, H., Lambrechts, M.C., Latorraca, C.O.C., Li, J., Cabrera Martimbianco, A.L., Riera, R., Rugulies, R., Sembajwe, G., Siegrist, J., Sillanmaki, L., Sumanen, M., Suominen, S., Ujita, Y., Vandersmissen, G., Godderis, L., 2021. The effect of exposure to long working hours on alcohol consumption, risky drinking and alcohol use disorder: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 146, 106205.

Panahi, D., Kakooei, H., Marioryad, H., Mehrdad, R., Golhosseini, M., 2011. Evaluation of exposure to the airborne asbestos in an asbestos cement sheet manufacturing industry in Iran. Environ. Monit. Assess. 178, 449–454.

Pandey, J.K.A., D., Gorain, S., Dubey, R.K., Vishwakarma, M.K., Mishra, K.K., Pal, A.K., Characterisation of respirable dust exposure of different category of workers in Jharia Coalfields. Arab. J. Geosci. 2017, 10.

Paulo, M.S., Adam, B., Akagwu, C., Akparibo, I., Al-Rifai, R.H., Bazrafshan, S., Gobba, F., Green, A.C., Ivanov, I., Kezic, S., Leppink, N., Loney, T., Modenese, A., Pega, F., Peters, C.E., Pruss-Ustun, A.M., Tenkate, T., Ujita, Y., Wittlich, M., John, S.M., 2019. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of occupational exposure to solar ultraviolet radiation and of the effect of occupational exposure to solar ultraviolet radiation on melanoma and non-melanoma skin cancer. Environ. Int. 126, 804–815.

Pega, F., Norris, S.L., Backes, C., Bero, L.A., Descatha, A., Gagliardi, D., Godderis, L., Loney, T., Modenese, A., Morgan, R.L., Pachito, D., Paulo, M.B.S., Scheepers, P.T.J., Schlunssen, V., Sgargi, D., Silbergeld, E.K., Sorensen, K., Sutton, P., Tenkate, T., Correa, T., da Silva, D., Ujita, Y., van Deventer, E., Woodruff, T.J., Mandrioli, D.-SPEO., 2020a. A tool for assessing risk of bias in studies estimating the prevalence of exposure to occupational risk factors from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 135, 105039.

Pega, F., Chartres, N., Guha, N., Modenese, A., Morgan, R.L., Martinez-Silveira, M.S., Loomis, D., 2020b. The effect of occupational exposure to welding fumes on trachea, bronchus and lung cancer: A protocol for a systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 145, 106089.

Pega, F., Nafradi, B., Momen, N.C., Ujita, Y., Streicher, K.N., Pruss-Ustun, A.M., Technical Advisory Group, Descatha, A., Driscoll, T., Fischer, F.M., Godderis, L., Kiiver, H.M., Li, J., Magnusson Hanson, L.L., Rugulies, R., Sorensen, K., Woodruff, T. J., 2021a. Global, regional, and national burdens of ischemic heart disease and stroke attributable to exposure to long working hours for 194 countries, 2000-2016: A systematic analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ Int 106595.

Pega, F., Momen, N.C., Ujita, Y., Driscoll, T., Whaley, P., 2021b. Systematic reviews and meta-analyses for the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 155, 106605.

Pega, F., Hamzaoui, H., Nafradi, B., Momen, N.C., 2022a. Global, regional and national burden of disease attributable to 19 selected occupational risk factors for 183 countries, 2000–2016: A systematic analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Scand. J. Work Environ. Health.

Pega, F., Momen, N.C., Gagliardi, D., Bero, L.A., Boccuni, F., Chartres, N., Descatha, A., Dzhambov, A.M., Godderis, L., Loney, T., Mandrioli, D., Modenese, A., van der

Molen, H.F., Morgan, R.L., Neupane, S., Pachito, D., Paulo, M.S., Prakash, K.C., Scheepers, P.T.J., Teixeira, L., Tenkate, T., Woodruff, T.J., Norris, S.L., 2022b. Assessing the quality of evidence in studies estimating prevalence of exposure to occupational risk factors: The QoE-SPEO approach applied in the systematic reviews from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ. Int. 161, 107136.

Pega, F., Momen, N.C., Bero, L., Whaley, P., 2022c. Towards a framework for systematic reviews of the prevalence of exposure to environmental and occupational risk factors. Environ. Health 21, 64.

Pega, F., Pabayo, R., Benny, C., Lee, E.-Y., Lhachimi, S., Liu, S.Y., 2022d. Unconditional cash transfers for reducing poverty and vulnerabilities: effect on use of health services and health outcomes in low- and middle-income countries. Cochrane Database Syst. Rev.

Perkins, R.A., Hargesheimer, J., Vaara, L., 2008. Evaluation of public and worker exposure due to naturally occurring asbestos in gravel discovered during a road construction project. J. Occup. Environ. Hyg. 5, 609–616.

Peters, C.E., Ge, C.B., Hall, A.L., Davies, H.W., Demers, P.A., 2015. CAREX Canada: an enhanced model for assessing occupational carcinogen exposure. Occup. Environ. Med. 72, 64–71.

Peters, S., Vermeulen, R., Fritschi, L., Musk, A.B., Reid, A., de Klerk, N., 2017. Trends in exposure to respirable crystalline silica (1986–2014) in Australian mining. Am. J. Ind. Med. 60, 673–678.

Phanprasit, W., Sujirarat, D., Chaikittiporn, C., 2009. Health risk among asbestos cement sheet manufacturing workers in Thailand. J. Med. Assoc. Thai. 92 (Suppl 7), S115–S120.

Piacitelli, G.M., Amandus, H.E., Dieffenbach, A., 1990. Respirable dust exposures in U.S. surface coal mines (1982–1986). Arch. Environ. Health 45, 202–209.

Prüss-Ustün, A., Wolf, J., Corvalán, C., Neville, T., Bos, R., Neira, M., 2017. Diseases due to unhealthy environments: An updated estimate of the global burden of disease attributable to environmental determinants of health. J. Public Health 39, 464–475.

Radnoff, D., Todor, M.S., Beach, J., 2014. Occupational exposure to crystalline silica at Alberta work sites. J. Occup. Environ. Hyg. 11, 557–570.

Radnoff, D.L., Kutz, M.K., 2014. Exposure to crystalline silica in abrasive blasting operations where silica and non-silica abrasives are used. Ann. Occup. Hyg. 58, 19–27.

Rando, R.J., Shi, R., Hughes, J.M., Weill, H., McDonald, A.D., McDonald, J.C., 2001. Cohort mortality study of North American industrial sand workers. III. Estimation of past and present exposures to respirable crystalline silica. Ann. Occup. Hyg. 45, 209–216.

Rappaport, S.M., Goldberg, M., Susi, P., Herrick, R.F., 2003. Excessive exposure to silica in the US construction industry. Ann. Occup. Hyg. 47, 111–122.

Rees, D., Cronje, R., du Toit, R.S., 1992. Dust exposure and pneumoconiosis in a South African pottery. 1. Study objectives and dust exposure. Br. J. Ind. Med. 49, 459–464.

Rokni, M.M., Hashemi, S.T., Asadi, S.M., Boogaard, P.J., Heibati, B., Yetilmezsoy, K., Abdul-Wahab, S.A., 2016. Risk assessment of workers exposed to crystalline silica aerosols. Human Ecol. Risk Assess.: Int. J. 22, 1678-1686.

Rugulies, R., Ando, E., Ayuso-Mateos, J.L., Bonafede, M., Cabello, M., Di Tecco, C., Dragano, N., Durand-Moreau, Q., Eguchi, H., Gao, J., Garde, A.H., Iavicoli, S., Ivanov, I.D., Leppink, N., Madsen, I.E.H., Pega, F., Pruss-Ustun, A.M., Rondinone, B. M., Sorensen, K., Tsuno, K., Ujita, Y., Zadow, A., 2019. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of exposure to long working hours and of the effect of exposure to long working hours on depression. Environ. Int. 125, 515–528.

Rugulies, R., Sørensen, K., Di Tecco, C., Bonafede, M., Rondinone, B.M., Ahn, S., Ando, E., Ayuso-Mateos, J.L., Cabello, M., Descatha, A., Dragano, N., Durand-Moreau, Q., Eguchi, H., Gao, J., Godderis, L., Kim, J., Madsen, I.E.H., Pachito, D.V., Sembajwe, G., Siegrist, J., Tsuno, K., Ujita, Y., Wang, J., Zadow, A., Iavicoli, S., Pega, F., 2021. The effect of exposure to long working hours on depression: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-Related Burden of Disease and Injury. Environ. Int. 155, 106629.

Saiyed, H.N., Ghodasara, N.B., Sathwara, N.G., Patel, G.C., Parikh, D.J., Kashyap, S.K., 1995. Dustiness, silicosis & tuberculosis in small scale pottery workers. Indian J. Med. Res. 102, 138–142.

Sanderson, W.T., Steenland, K., Deddens, J.A., 2000. Historical respirable quartz exposures of industrial sand workers: 1946–1996. Am. J. Ind. Med. 38, 389–398.

Sayler, S.K., Long, R.N., Nambunmee, K., Neitzel, R.L., 2018. Respirable silica and noise exposures among stone processing workers in northern Thailand. J. Occup. Environ. Hyg. 15, 117–124.

Scarselli, A., Corfiati, M., Marzio, D.D., Iavicoli, S., 2014. Evaluation of workplace exposure to respirable crystalline silica in Italy. Int. J. Occup. Environ. Health 20, 301–307.

Scarselli, A., Corfiati, M., Di Marzio, D., 2016. Occupational exposure in the removal and disposal of asbestos-containing materials in Italy. Int Arch Occup Environ Health 89, 857–865.

Schonfeld, S.J., Kovalevskiy, E.V., Feletto, E., Bukhtiyarov, I.V., Kashanskiy, S.V., Moissonier, M., Straif, K., McCormack, V.A., Schuz, J., Kromhout, H., 2017. Temporal Trends in Airborne Dust Concentrations at a Large Chrysotile Mine and its Asbestos-enrichment Factories in the Russian Federation During 1951–2001. Ann Work Expo Health 61, 797–808.

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., Group, P.-P., 2015. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ 350, g7647.

Siltanen, E., Koponen, M., Kokko, A., Engström, B., Reponen, J., 1976. Dust exposure in Finnish foundries. Scand. J. Work Environ. Health 2 (Suppl 1), 19–31.

Stevens, G.A., Alkema, L., Black, R.E., Boerma, J.T., Collins, G.S., Ezzati, M., Grove, J.T., Hogan, D.R., Hogan, M.C., Horton, R., Lawn, J.E., Marusic, A., Mathers, C.D., Murray, C.J., Rudan, I., Salomon, J.A., Simpson, P.J., Vos, T., Welch, V., 2016. Guidelines for accurate and transparent health estimates reporting: the GATHER statement. Lancet 388, e19–e23.

Swanepoel, A., Swanepoel, C., Rees, D., 2018. Determinants of respirable quartz exposure in farming. J. Occup. Environ. Hyg. 15, 71–79.

Swanepoel, A.J., Kromhout, H., Jinnah, Z.A., Portengen, L., Renton, K., Gardiner, K., Rees, D., 2011. Respirable dust and quartz exposure from three South African farms with sandy, sandy loam, and clay soils. Ann. Occup. Hyg. 55, 634–643.

Tarres, J., Alberti, C., Martinez-Artes, X., Abos-Herrandiz, R., Rosell-Murphy, M., Garcia-Allas, I., Krier, I., Cantarell, G., Gallego, M., Canela-Soler, J., Orriols, R., 2013. Pleural mesothelioma in relation to meteorological conditions and residential distance from an industrial source of asbestos. Occup. Environ. Med. 70, 588–590.

Tavakol, E., Azari, M., Zendehdel, R., Salehpour, S., Khodakrim, S., Nikoo, S., Saranjam, B., 2017. Risk Evaluation of Construction Workers' Exposure to Silica Dust and the Possible Lung Function Impairments. Tanaffos 16, 295–303.

Teixeira, L.R., Azevedo, T.M., Bortkiewicz, A., Correa da Silva, D.T., de Abreu, W., de Almeida, M.S., de Araujo, M.A.N., Gadzicka, E., Ivanov, I.D., Leppink, N., Macedo, M.R.V., de, S.M.E.M.G., Pawlaczyk-Luszczynska, M., Pega, F., Pruss-Ustun, A.M., Siedlecka, J., Stevens, G.A., Ujita, Y., Braga, J.U., 2019. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of exposure to occupational noise and of the effect of exposure to occupational noise on cardiovascular disease. Environ Int 125, 567–578.

Teixeira, L.R., Pega, F., Dzhambov, A.M., Bortkiewicz, A., da Silva, D.T.C., de Andrade, C.A.F., Gadzicka, E., Hadkhale, K., Iavicoli, S., Martinez-Silveira, M.S., Pawlaczyk-Luszczynska, M., Rondinone, B.M., Siedlecka, J., Valenti, A., Gagliardi, D., 2021a. The effect of occupational exposure to noise on ischaemic heart disease, stroke and hypertension: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-Related Burden of Disease and Injury. Environ. Int. 106387.

Teixeira, L.R., Pega, F., de Abreu, W., de Almeida, M.S., de Andrade, C.A.F., Azevedo, T. M., Dzhambov, A.M., Hu, W., Macedo, M.R.V., Martinez-Silveira, M.S., Sun, X., Zhang, M., Zhang, S., Correa da Silva, D.T., 2021b. The prevalence of occupational exposure to noise: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury.

Tenkate, T., Adam, B., Al-Rifai, R.H., Chou, B.R., Gobba, F., Ivanov, I.D., Leppink, N., Loney, T., Pega, F., Peters, C.E., Pruss-Ustun, A.M., Silva Paulo, M., Ujita, Y., Wittlich, M., Modenese, A., 2019. WHO/ILO work-related burden of disease and injury: Protocol for systematic reviews of occupational exposure to solar ultraviolet radiation and of the effect of occupational exposure to solar ultraviolet radiation on cataract. Environ. Int. 125, 542–553.

Tjoe Nij, E., Hilhorst, S., Spee, T., Spierings, J., Steffens, F., Lumens, M., Heederik, D., 2003. Dust control measures in the construction industry. Ann. Occup. Hyg. 47, 211–218.

Tjoe Nij, E., Höhr, D., Borm, P., Burstyn, I., Spierings, J., Steffens, F., Lumens, M., Spee, T., Heederik, D., 2004. Variability in quartz exposure in the construction industry: implications for assessing exposure-response relations. J. Occup. Environ. Hyg. 1, 191–198.

Tripathy, D.D., Badu, A., Kanungo, R., 2015. Assessment and modelling of dust concentration in an opencast coal mine in India. Global Nest J. 17, 825-834.

Ulvestad, B., Bakke, B., Melbostad, E., Fuglerud, P., Kongerud, J., Lund, M.B., 2000. Increased risk of obstructive pulmonary disease in tunnel workers. Thorax 55, 277–282.

Ulvestad, B., Bakke, B., Eduard, W., Kongerud, J., Lund, M.B., 2001a. Cumulative exposure to dust causes accelerated decline in lung function in tunnel workers. Occup. Environ. Med. 58, 663–669.

Ulvestad, B., Lund, M.B., Bakke, B., Djupesland, P.G., Kongerud, J., Boe, J., 2001b. Gas and dust exposure in underground construction is associated with signs of airway inflammation. Eur. Respir. J. 17, 416–421.

United Nations, D.o.E.a.S.A.S.D.-S.D. International Standard Industrial Classification of All Economic Activities- Revision 4. Statistical Papers. United Nations, New York: United Nations.

van Deurssen, E., Pronk, A., Spaan, S., Goede, H., Tielemans, E., Heederik, D., Meijster, T., 2014. Quartz and respirable dust in the Dutch construction industry: a baseline exposure assessment as part of a multidimensional intervention approach. Ann. Occup. Hyg. 58, 724–738.

van Deurssen, E., Meijster, T., Oude Hengel, K.M., Boessen, R., Spaan, S., Tielemans, E., Heederik, D., Pronk, A., 2015. Effectiveness of a Multidimensional Randomized Control Intervention to Reduce Quartz Exposure Among Construction Workers. Ann. Occup. Hyg. 59, 959–971.

Verma, D.K., Rajhans, G.S., Malik, O.P., des Tombe, K., 2014. Respirable dust and respirable silica exposure in Ontario gold mines. J. Occup. Environ. Hyg. 11, 111–116.

Wang, L., Liu, X., Yu, D., Wang, L., Zhou, X., Zi, Y., 2015. Current situation of prevention and treatment of silicosis in Jinshan District of Shanghai, China. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi 33, 456–458.

Wang, X., Yano, E., Qiu, H., Yu, I., Courtice, M.N., Tse, L.A., Lin, S., Wang, M., 2012. A 37-year observation of mortality in Chinese chrysotile asbestos workers. Thorax 67, 106–110.

Watts Jr., W.F., Huynh, T.B., Ramachandran, G., 2012. Quartz concentration trends in metal and nonmetal mining. J. Occup. Environ. Hyg. 9, 720–732.

Weeks, J.L., Rose, C., 2006. Metal and non-metal miners' exposure to crystalline silica, 1998–2002. Am. J. Ind. Med. 49, 523–534.

Wilmoth, R.C.T., Taylor, M.S., 1994. Asbestos release from the demolition of two schools in Fairbanks, Alaska. Appl. Occup. Environ. Hygiene 9, 409-417.

World Health Organization. Global Health Estimates 2016. 2018.
World Health Organization, 2021. The effect of occupational exposure to solar ultraviolet radiation on malignant skin melanoma and non-melanoma skin cancer: a systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. World Health Organization, Geneva.
World Health Organization; International Labour Organization, 2021a. WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury, 2000–2016: Technical Report with Data Sources and Methods. World Health Organization, Geneva.
World Health Organization; International Labour Organization, 2021b. WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury, 2000–2016: Global Monitoring Report. World Health Organization, Geneva.
Woskie, S.R., Kalil, A., Bello, D., Virji, M.A., 2002. Exposures to quartz, diesel, dust, and welding fumes during heavy and highway construction. AIHA J (Fairfax, Va) 63, 447–457.
Yassin, A., Yebesi, F., Tingle, R., 2005. Occupational exposure to crystalline silica dust in the United States, 1988–2003. Environ. Health Perspect. 113, 255–260.
Yingratanasuk, T., Seixas, N., Barnhart, S., Brodkin, D., 2002. Respiratory health and silica exposure of stone carvers in Thailand. Int. J. Occup. Environ. Health 8, 301–308.
Zarei, F., Rezazadeh Azari, M., Salehpour, S., Khodakarim, S., Omidi, L., Tavakol, E., 2017. Respiratory Effects of Simultaneous Exposure to Respirable Crystalline Silica Dust, Formaldehyde, and Triethylamine of a Group of Foundry Workers. J Res Health Sci 17, e00371.
Zhuang, Z., Hearl, F.J., Odencrantz, J., Chen, W., Chen, B.T., Chen, J.Q., McCawley, M. A., Gao, P., Soderholm, S.C., 2001. Estimating historical respirable crystalline silica exposures for Chinese pottery workers and iron/copper, tin, and tungsten miners. Ann. Occup. Hyg. 45, 631–642.
Zwillinger, D.K., 2000. Standard probability and statistics tables and formulae. Chapman & Hall/CRC, Boca Raton, FL.