A systematic review of respirable dust and respirable crystalline silica dust concentrations in copper mines: guiding Zambia's development of an airborne dust monitoring programme

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ABSTRACT

Background: Workers in copper mines are exposed to respirable dust (RD) and respirable crystalline silica (RCS), which could lead to the development of silicosis. With the expected increase in copper production in the next two decades due to the world's green energy pathway, the number of miners exposed to RCS and incidents of exposure exceeding the recommended occupational exposure and other limits may increase. However, data for RD and RCS concentrations in the copper mining industry are limited.

Objective: The objectives of this study were to assess the current state of knowledge about exposure to RD and RCS in copper mines, and to provide recommendations for the development of an airborne dust monitoring programme in Zambia.

Methods: A systematic literature review was conducted, using the PRISMA methodology. The following online databases were searched for relevant research articles about RD and RCS in copper mines: Clarivate's Web of Science, Google Scholar, PubMed, Science Direct, EBSCO Host, and Scopus, using keywords and phrases with boolean operators. Articles were eligible for inclusion regardless of the sampling method used to measure airborne RD and/or RCS (personal exposure or area monitoring), were published in the period 1970–2023, and met the quality requirements.

Results: After full-text screening, nine out of 6 710 potential articles remained. We found that area and personal RD and RCS data in copper mines are not widely documented in the open-access online literature. For personal RCS data, exposure exceeded the occupational exposure or other recognised limits in most sites; the highest personal RCS exposures occurred in sections of the mine where ore was crushed and transported. For mines that only conducted area monitoring of RD, the airborne dust concentrations that were potentially available for personal exposure were relatively low, compared to the RD exposure limit of 3 mg/m^3. Overexposure to RCS occurred even though personal exposure to RD complied with applicable limits in most cases.

Conclusion: We found evidence of personal overexposure to RCS in copper mines, globally. Assessment of RD concentrations alone (even when exposure is under control) is not adequate to protect workers against overexposure to RCS. Zambia needs to develop an RCS monitoring programme for the copper mining industry. The programme should be based on established standards such as the European Standardisation Committee (CEN) standard (BS EN 689:2018), or the South African Mining Industry Code of Practice as the socio-economic conditions of miners are similar in Zambia and South Africa.

INTRODUCTION

Occupational exposure in developing countries remains a challenge and workers in different industries are exposed to a variety of occupational health stressors. One of the most widely studied occupational stressors is airborne dust. Numerous studies of exposure to airborne dust have been conducted in occupational environments such as mining, construction, and pottery.[1] Exposure assessment of airborne dust in an occupational setting such as a mine should include respirable crystalline silica (RCS). As one of the most abundant minerals on earth, it is a component of the dust generated by all mining activities, although the percentage of RCS in the dust differs between sites. Excessive exposure to RCS can lead to the development of adverse health effects, such as silicosis and other occupational lung diseases (OLDs).[2]

Exposure to respirable dust also poses a risk to workers. Dust particulates in the respirable fraction can be deposited deep into the alveoli region of the lungs, which may lead to more severe adverse health effects than those associated with dust deposition in the upper regions of the respiratory tract.[3] The respirable fraction refers to the particulate mass fraction of inhaled particles that penetrate the unciliated airways of the respiratory tract.[4]

Silicosis is a progressive, irreversible fibrotic lung disease. Although the Global Burden of Disease study identified 23 695 incident cases of silicosis in 2017, this is an underestimate because of deficiencies in reporting programmes and limited attention, in many countries, given to sectors other than mining.[5] Several studies have investigated silicosis in copper mines and reported a correlation between exposure to RCS and the development of silicosis and other OLDs.[1,6-8]

Several RCS exposure assessment studies have been carried out across different mining commodities such as coal and gold.[9,10] The percentage of RCS in bulk samples differs across commodities[11,12] and has been well described in these mines. However, there is limited published literature describing results from comprehensive RCS exposure assessment studies in copper mines. Fifty-four countries in the world mine copper, with many mining sites among them.[13] With global copper output anticipated to increase by 40% in the next two decades,[14] due to the pace of electrification and the need for clean energy, this may lead to an increased number of workers at risk of overexposure to respirable dust (RD) and RCS.

Zambia, one of the top copper producing countries in the world, has no national monitoring programme or legislated standard for exposure to airborne dust. Each mining company runs its own programme with standards adopted from the country of ownership; most of the copper mines are owned and run by international companies. Currently, there are two commercial copper mines that are state-owned and each has at least two mining sites.

The country intends to double its copper production by 2031 to meet the global demand caused by the world's green energy pathway. A national monitoring programme for occupational exposure to airborne dust is needed, to address the potential health challenges associated with this increase in copper production and the associated increase in the size of the mining workforce.

This systematic review was undertaken to assess the available knowledge on RD and RCS measurements in copper mines, and provide recommendations for the Zambian Government to consider for its development of an airborne dust monitoring programme.

METHODS

Search strategy

A search for relevant literature was conducted, following the 'preferred reporting items for systematic reviews and meta-analyses' (PRISMA) method.[15] The following online search engines were used to search for published peer-reviewed research papers: Clarivate's Web of Science, Google Scholar, PubMed, Science Direct, EBSCO Host, and Scopus.

The following keywords and phrases with boolean operators were used in the search: 'dust exposure', 'respirable crystalline silica', 'respirable dust', 'exposure to silica', and 'dust'. The word 'copper mine' was coupled to all the search strings, using the boolean operator, 'AND'. The period used to search for literature was 1 January 1970 to 30 August 2023.

After the search was conducted and papers were selected, the web-based tool EPPI-Reviewer (beta version) (University College London, England) was used to review the papers. This programme offers coding, screening, and direct import of studies from the databases that are searched.[16] The software was used to screen the titles and abstracts of articles. For full-text review, a Microsoft Office Excel spreadsheet was designed; all pertinent information was recorded.

Duplicate articles were eliminated before the screening process. This was accomplished by setting the similarity index to 90% in the EPPI-Reviewer web tool. Papers with a similarity index ≥ 90% were identified by the software as duplicates and were excluded. The titles, author(s), years of publication, and abstracts of all papers were also manually screened and compared. If the details were similar, then the papers were considered to be duplicates. This manual process was followed because the EPPI-Reviewer tool considers two articles to be different even when they have a difference of a comma in the title.

The following inclusion criteria were applied in the title and abstract screening stage:

- Original research article
- Written in English
- Addresses measurements of RD or RCS using any sampling method
- Study conducted in a copper mine; if a combination of copper and other commodity mines were studied, then the RD and RCS concentrations for the copper mine, specifically, needed to be available

Eligibility for full-text review was based on two additional requirements, viz.:

- Presentation of concentrations of RD and/or RCS (personal or area monitoring data)
- The article must have met the quality requirements

Articles that reported only area measurements of RD and RCS were included, because they indicate the potential of personal exposure even though they cannot legally be used to estimate exposure limits.

Quality assessment

Two authors independently reviewed the articles at all stages (title, abstract, and full-text screening) for inclusion; disagreements were resolved through discussion with a third reviewer. The quality of the articles selected for full-text review was appraised using the 'standard quality assessment criteria for evaluating primary research papers from a variety of fields' tool (QualSyst).[17] This assessment tool is suited for assessing the quality of studies with a broad range of designs. The authors scored the articles on a scale, as follows: > 80% was rated as high quality, 50% to 79% was considered moderate quality, and below 50% as poor quality. A rating of at least moderate qualified the article for inclusion in the final review.[17]

Data extraction

The extracted data (RD and RCS exposure data, area concentrations of RD and RCS, sampling method, monitoring standard, etc.) were uploaded to an Excel sheet. Compliance of personal exposure to RD and RCS with the relevant occupational exposure limits (OELs) and other limits was evaluated. Area RD and RCS concentrations were used to estimate the potential for exposure. The analytical standard used for quantification of RD and RCS in each article was noted.

RESULTS

Description of the papers included in the systematic review

The detailed selection procedure is presented in Figure 1. Based on the search strategy, using the six online databases, 76 articles were initially identified from Web of Science, 2 790 from Google Scholar, 943 from PubMed, 43 from Science Direct, 2 292 from Ebsco Host, and 32 from Scopus.

Following the full-text screening, all articles met the quality requirements; the highest and lowest quality ratings were 95.45% and 54.55%, respectively. Nine articles were included in the systematic review. The numbers of articles excluded at each stage of screening are shown in Figure 1, and the extracted information is summarised in Table 1. The majority of the studies were published in the last 20 years (2004–2023); the oldest was published in 1989.

The majority of the articles included in the review used 0.1 mg/m^3 as the exposure limit for an 8-hr time weighted average (TWA) for personal exposure to RCS. For personal exposure to RD, only one study reported the 8-hr TWA exposure limit, which was set at 3 mg/m^3. Most articles included airborne RD concentrations conducted using area monitoring.

Most of the mines studied were in the United States of America and used an aluminium cyclone as the size-selective sampling head. The studies from China and Zambia used a nylon cyclone. These size-selective sampling heads were used regardless of the sampling method (area or personal monitoring).

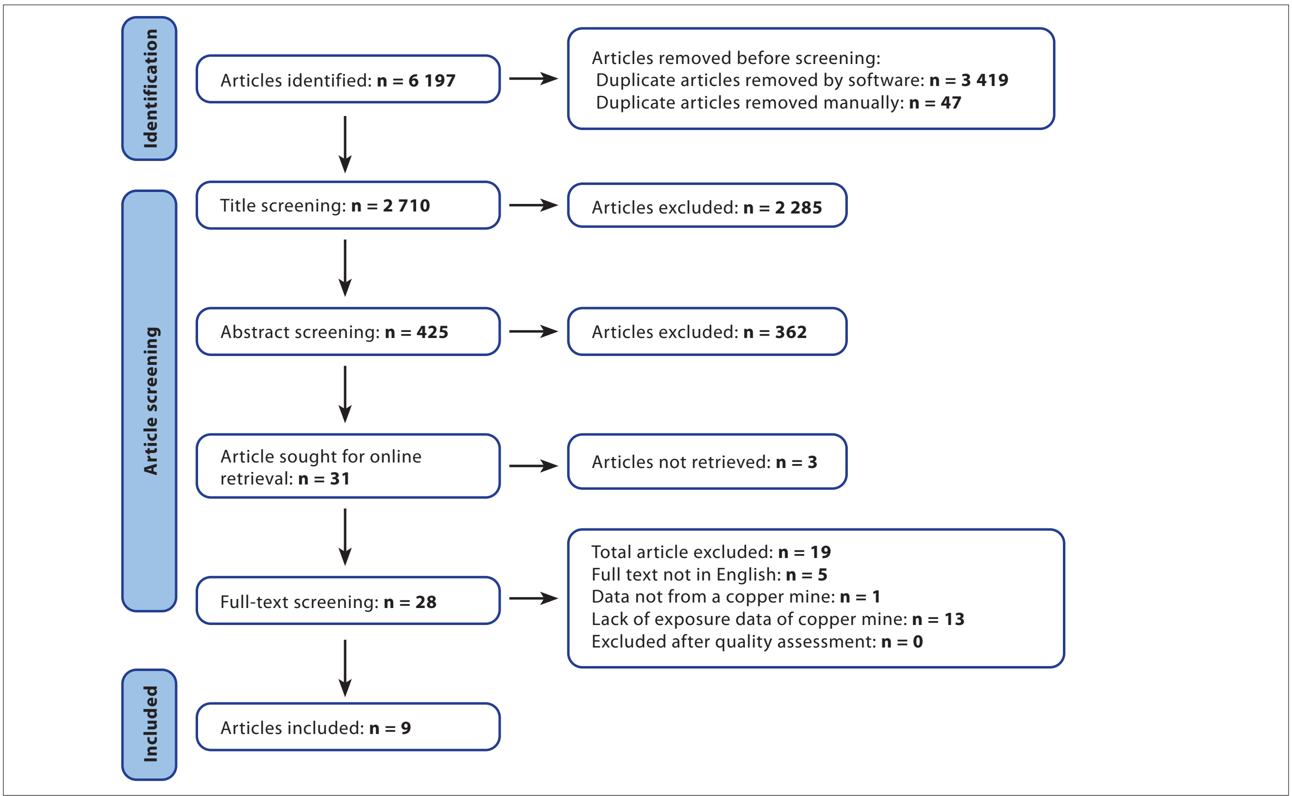

Figure 1. PRISMA flow diagram, illustrating the article selection procedure for the review

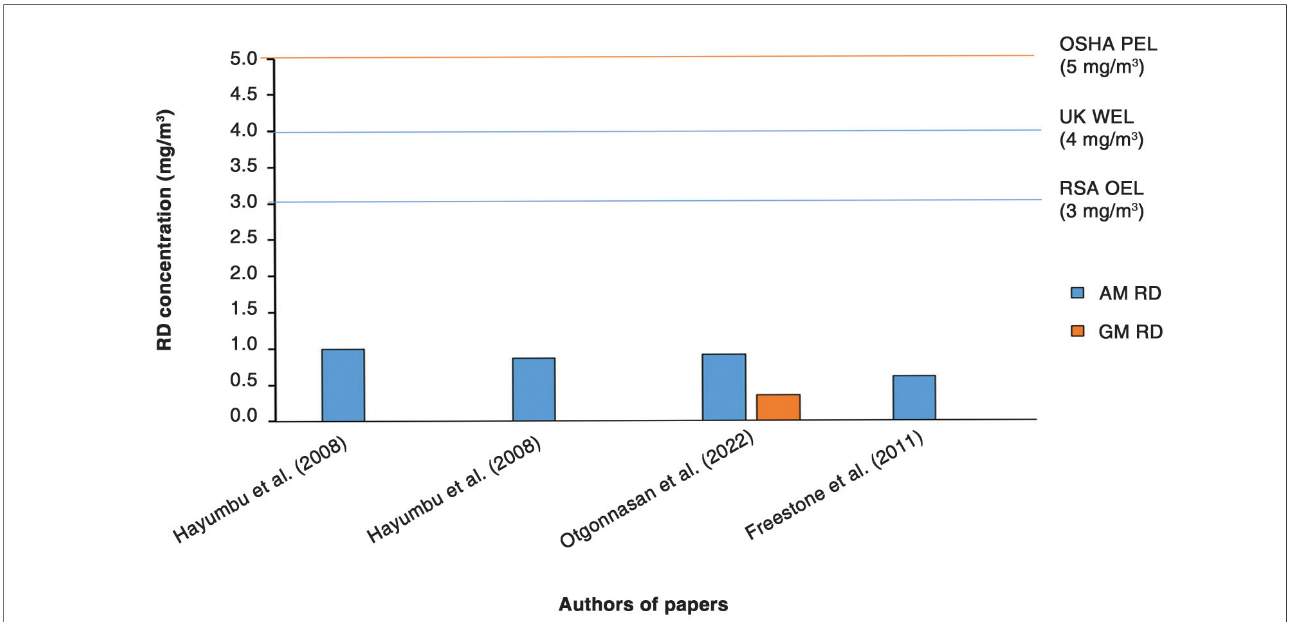

Figure 2. AMs and GMs of personal exposures to respirable dust reported in papers included in the systematic review

AM: arithmetic mean, GM: geometric mean, OEL: occupational exposure limit, OSHA: Occupational Safety and Health Administration, PEL: permissible exposure limit, RD: respirable dust, RSA: Republic of South Africa, UK: United Kingdom, WEL: workplace exposure limit
Hayumbu et al. (2008)[23] and Freestone et al. (2011)[22] did not report the GM for RD.

Table 1. Summarised information from the nine studies included in the systematic review

Author(s)	Country	Aim	Findings	Sampling method/# samples	Type of sampling head	Respirable dust Range (mg/m³)	Respirable dust AM/GM	Respirable dust EL/% above EL	Respirable crystalline silica dust AM/ GM	Respirable crystalline silica dust Range (mg/m³)	Respirable crystalline silica dust EL used	Respirable crystalline silica dust % above EL	Respirable crystalline silica dust % in sample
Misra et al., 2023[18]	USA	RCS exposures among all M/NM mines	Identified highly exposed groups	Personal/ 639[a]	-	-	-	-	0.070/-	-	0.1 (MSHA PEL)	17.8	10
Otgonnasan et al., 2022[19]	Mongolia	Personal exposure to RD and RCS	Risk of over-exposure to RD and RCS	Personal/ 581[b], 264[a]	Aluminium cyclone	0.020–18.430	0.91/ 0.35	(3 MNS-PEL)/5.9%	0.049/ 0.090	0.001–0.588	0.1 (MNS-PEL)	14.8	-
Cauda et al., 2018[20]	USA	Assess the DoF-FTIR technique for estimation of RCS	DoF-FTIR can be used to estimate RCS	Static	Aluminium cyclone	-	-	-	-	-	-	-	18[c]
Gautam et al., 2016[21]	India	Dispersion behav-iour of PM	Equation predicting particle travel time with depth	Static	Particle monitor (Grimm)	0.016–0.197	-	-	-	-	-	-	-
Freestone et al., 2011[22]	USA	Use DRI to predict hazardous metal concentrations	DRI not suitable for measurement of metal concentration	Static/16[b]	Aluminium cyclone	0.146–0.917	0.605/ -	-	-	-	-	-	-
				Static/16[b]	Particle monitor (Haz-Dust)	0.043–0.040	0.203/ -	-	-	-	-	-	-
Zubieta et al., 2009[6]	Mexico	Assess work-related hazards	51% of settled dust was RD	Settled dust	-	-	-	-	-				23% Q in TD
Hayumbu et al., 2008[23d]	Zambia	Characterise RD and RCS exposure	There was over-exposure to RCS	Personal/ 101[a,b]	Nylon cyclone	0.000–7.674	0.99/ -	-	0.143/-	0.000–1.302	0.025 (ACGIH TLV)	78.0	59
				Personal/ 102[a,b]	Nylon cyclone	0.000–6.944	0.868/ -	-	0.060/-	0.000–0.317	0.025 (ACGIH TLV)	53.0	26
Wu et al., 1992[24e]	China	Compare Chinese sampling methods and strat-egies to NIOSH	Bias observed; linear model accounted for 77% of variability	Static	Nylon cyclone	0.460–1.000	-	-	-	-	-	-	10
						0.190–5.100	-	-	-	-	-	-	24
						2.900–5.800	-	-	-	-	-	-	14
						0.130–0.220	-	-	-	-	-	-	11
Romo-Kroger et al., 1989[25]	Chile	Determine Mg, Al, Si, K concentrations	4 out of 5 elements exceeded exposure limit	Personal	Racal helmet	-	-	-	0.189/-	-	0.045	4 times > OEL	-

ACGIH: American Conference of Governmental Industrial Hygienists, AM: arithmetic mean, Al: aluminium, CS: crystalline silica, DoF-FTIR: direct on filter-Fourier-transform infrared spectroscopy, DRI: direct-reading instrument, EL: exposure limit (used in study), GM: geometric mean, K: potassium, M: metal, Mg: magnesium, MNS: Mongolian National Standard, MSHA: Mine Safety and Health Administration, NM: non-metal, OEL: occupational exposure limit, PEL: permissible exposure limit, PM: particulate matter, Q: quartz, RCS: respirable crystalline silica, RD: respirable dust, Si: silicon, TD: total dust, TLV: threshold limit value, USA: United States of America

[a]RCS samples, [b]RD samples, [c]percentage silica in RD, [d]two results from two mining sites, [e]four results from four mining sites

Respirable dust concentrations

Personal exposure to RD across mining sites is shown in Figure 2. All the mining sites did not report AM personal exposure to RD that exceeded the Occupational Safety and Health Administration's (OSHA's) permissible exposure limit (PEL) of 5 mg/m^3, the United Kingdom's Health and Safety Executive's workplace exposure limit (WEL) of 4 mg/m^3, and the Republic of South Africa mining industry's (SAMI's) OEL of 3 mg/m^3.

In all the studies that reported personal exposure to RD, the arithmetic mean (AM) and geometric mean (GM) were below the relevant exposure levels (Figure 2). However, in each mine in which RD was measured, there were incidents of overexposure when considering individual personal exposure values. For example, the AM and GM personal exposures to RD in the paper by Otgonnasan et al. (2022)[19] were 0.91 and 0.35 mg/m^3, respectively, while the highest personal exposure concentration was 18.43 mg/m^3. Hayumbu et al. (2008)[23] also reported maximum personal exposure to RD of 7.674 mg/m^3 and 6.944 mg/m^3 for the two mine sites studied.

In two of the nine articles, sensor instruments were used to measure airborne RD. One of the instruments was the GRIMM Model 1.108 (Durag Group, Hamburg, Germany), which uses the principle of light scattering or extinction to detect and count aerosols, with an algorithm for sizing.[21] It is an area monitoring instrument and supports a filter for further chemical analysis. The other instrument was the Haz-Dust EPAM 5000 (SKC Ltd., Blandford, United Kingdom), which is also used for area monitoring. It has interchangeable sampling heads for PM10, PM2.5 and PM1.0 monitoring. In the study by Freestone et al. (2011),[22] the instrument could not be used to estimate exposure to some metals, while Gautam et al. (2016)[21] successfully used it to estimate the dispersion behaviour of aerosols.

Respirable crystalline silica concentrations

All the five mining sites included in this review reported AMs of RCS exposure concentrations that exceeded the health-based American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 0.025 mg/m^3. The AMs of personal RCS exposure from two mining sites exceeded the European Union (EU) and South Africa OELs of 0.1 mg/m^3, as shown in Figure 3.

To determine the percentage of silica in their samples, Hayumbu et al. (2008)[23] and Wu et al. (1992)[24] used bulk samples; Cauda et al. (2018)[20] and Misra et al. (2023)[18] used RD samples; and Zubieta et al. (2009)[6] used settled dust samples. The articles by Hayumbu et al. (2008)[23] and Wu et al. (1992)[24] appear more than once in Figure 4, because they included more than one mine site in the article describing the study. The percentage of silica reported in the articles included in this systematic review ranged from 10% to 59% (AM = 21.6%). This was calculated regardless of whether the silica content was determined from bulk, personal, or settled dust.

DISCUSSION

Although the copper mining industry has been in operation in Zambia since the 1930s,[23] little has been done, through legislation, to protect workers from overexposure to RD and RCS. The country has no airborne dust-monitoring programme and is yet to set OELs for RD and RCS exposure. This systematic review was undertaken to assess the available RD and RCS measurements in copper mines, reported in published scientific articles, and to provide recommendations for the Zambian Government to consider for its development of an airborne dust-monitoring programme. Data such as airborne dust monitoring standards, airborne dust sampling methods, area airborne RD concentrations, and whether personal exposure to RD and RCS was under control, was noted.

Exposure to respirable dust

For the mines that reported personal exposures to RD, the AMs did not exceed the applicable occupational exposure limit used. However, all three mining sites where personal exposure to RD was measured reported maximum exposures exceeding 5 mg/m^3, which is almost double the SAMI OEL for RD. A worker at the concentrator in the Otgonnasan et al. (2022)[19] study experienced the highest exposure to RD of 18.43 mg/m^3. Thus, all the mines that monitored personal exposure to RD showed evidence of overexposure to RD, as they are all not compliant with the OSHA-PEL, UK-WEL, and RSA-OEL for RD, even though the AM of personal exposure to RD did not exceed the respective exposure limits.

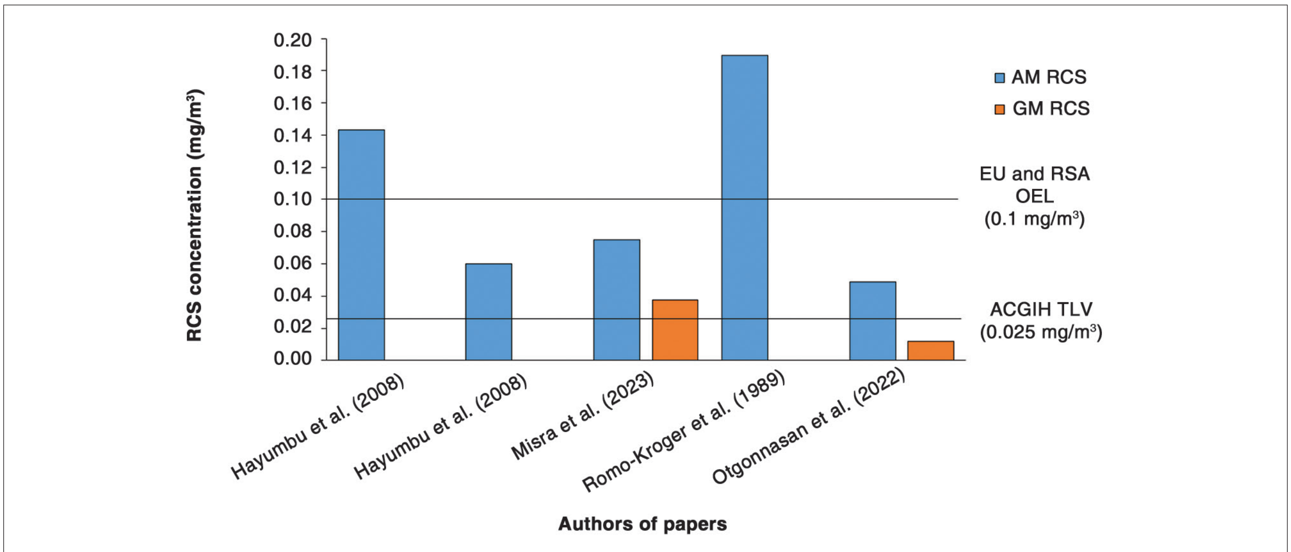

Figure 3. AMs and GMs of personal RCS exposure measurements for copper mines reported in papers included in the systematic review

ACGIH: American Conference of Governmental Industrial Hygienists, AM: arithmetic mean, EU: European Union, GM: geometric mean, OEL: occupational exposure limit, RCS: respirable crystalline silica, RSA: Republic of South Africa, TLV: threshold limit value
Hayumbu et al. (2008)[23] and Romo-Kroger et al. (1989)[25] did not report the GM for RCS.

In one of the nine papers included in this systematic review, an exposure limit of 3 mg/m^3 was used for personal RD exposure compliance testing. If this exposure limit is used for a comparison with area monitoring measurements, then workers in the two mine sites from the four studied by Wu et al. (1992)[24] have potential for overexposure to RD, because the range of airborne RD concentrations for the two mines was 0.19–5.10 mg/m^3 and 2.90–5.80 mg/m^3, respectively. Thus, of the 10 mine sites where RD concentrations were reported, three had evidence of personal overexposure to RD and two had potential for personal overexposure to RD (based on area concentrations).

Since the studies included in this systematic review showed evidence of overexposure to RD in copper mines, Zambia should consider establishing an airborne RD personal exposure monitoring programme. A stringent 8-hr TWA exposure limit of 3 mg/m^3 should be adopted.

Exposure to respirable crystalline silica

Most of the mines reported RCS dust concentrations that exceeded the OELs that they used as guidelines. One measurement above the exposure limit means that exposure is not under control for that section of the mine.[26] Thus, there was a clear indication of overexposure to RCS in copper mines, worldwide. Yet, there are only a few studies that have published reports of personal exposure to RCS in copper mines in open-access scientific journals.

Otgonnasan et al. (2022)[19] established that workers in the sample preparation department were exposed to the highest levels of RCS, and that maintenance workers, operators, drill mechanics, and those working at the crusher had exposure levels exceeding the Mongolian National Standard- (MNS-) PEL. However, in most of the articles included in this systematic review, most of the overexposure RCS measurements were for workers in the concentrator section. Personal exposures reported by Hayumbu et al. (2008)[23] also exceeded applicable exposure limits. The articles included in this systematic review provide evidence for personal overexposure to RCS in copper mines.

The AM (%) of RCS in the mines included in this systematic review was 21.6% (AM) (10–59%), which is comparable to the concentrations reported by Chubb and Cauda (2017) in three gold mines, viz. 21.6% (9–37%).[11] In the four coal mines studied by Keles and Sarver (2022),[12] the percentage of RCS measured from area monitoring was 12.45% (1.45–27.6%). This relatively high percentage of RCS in the airborne RD has implications for RD and RCS monitoring programmes. If, for example, a worker works in an area where the proportion of RCS in the RD is 21.6% and he/she is exposed to an RD concentration of 1 mg/m^3 (30% of the RD OEL of 3 mg/m^3), then he/she would be exposed to 0.216 mg/m^3 RCS (216% the SAMI OEL for RCS of 0.1 mg/m^3). This means that RD sampling programmes will not be able to predict high personal exposure to RCS, which is a challenge to mines that routinely monitor personal exposure to RD only.

Routine personal RD exposure monitoring is not adequate for predicting personal exposure to RCS. Since silicosis is solely due to overexposure to RCS, Zambia should consider a mandatory routine personal RCS monitoring programme in copper mines.

The EU and SAMI 8-hr TWA RCS exposure limit of 0.1 mg/m^3 may not adequately protect miners against the adverse health effects of exposure to RCS. This exposure limit is four times higher than the ACGIH's health-based 8-hr TWA for RCS exposure of 0.025 mg/m^3. In the United States, the 8-hr TWA for RCS was reduced to 0.05 mg/m^3 in 2016.[5] In 2009, Canada also reduced its 8-hr TWA OEL for RCS to 0.025 mg/m^3 for both quartz and cristobalite, from 0.1 mg/m^3 and 0.05 mg/m^3, respectively.[5] South Africa is also considering reducing its 8-hr TWA OEL for RCS from 0.1 to 0.05 mg/m^3.[27]

Zambia should consider the factors that led to these reductions (and considerations for reduction) and socio-economic factors in the country when settings its own exposure limits for RD and RCS.

Exposure assessment standards

The most widely adopted analytical methods in the articles included in the systematic review were the National Institute for Occupational Safety and Health (NIOSH) methods (0600, and 7500 or 7602) for quantification of RD and RSC, respectively.[19,23] Although the authors describe the analytical standards used in the studies, the majority of the studies in which RD personal exposure assessments were conducted did not specify the method used for assigning workers to similar exposure groups (SEGs). An SEG can be defined as a group of workers having the same general exposure to an agent, because of similarity and frequency

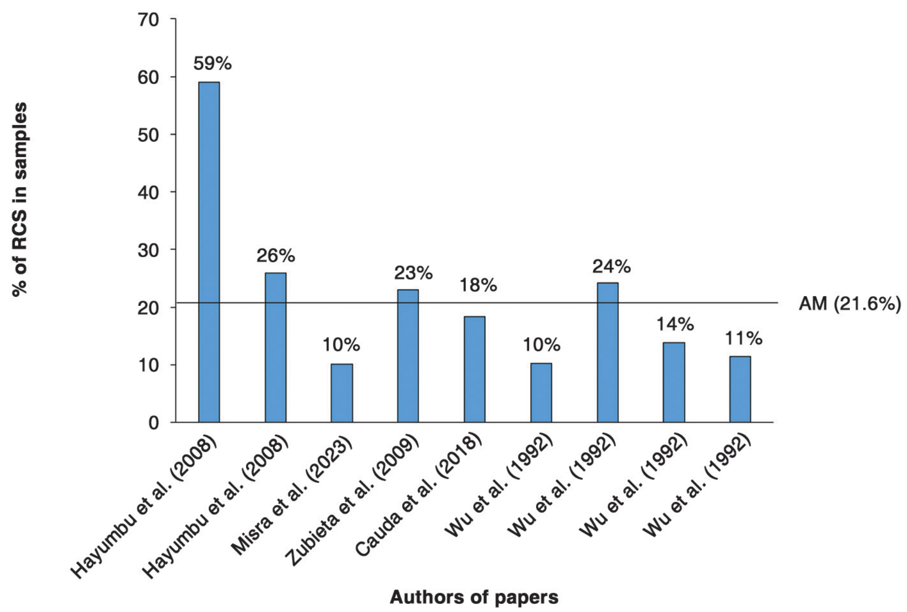

Figure 4. Percentage of silica in dust samples as reported by included studies

AM: arithmetic mean, RCS: respirable crystalline silica of the task(s) they perform, and similarity in processes and materials with which they work.[26] In some studies, the whole mine was treated as a single SEG. The SEGs represent small sub-populations within the workforce: 5% of workers, with a minimum of five workers, can be selected randomly from each SEG for personal sampling; the results will apply to the whole SEG.[28] This reduces variability of the results and the number of samples that need to be collected, and subsequently reduces the cost of the monitoring programme.

Zambia should also adopt the NIOSH methods 0600 for RD, and 7500 or 7602 for RCS quantifications, as they are widely used. The European Standardisation Committee (CEN) (BS EN 689:2018) standards can also be adopted for assigning workers to SEGs and for compliance testing. The CEN standard is more widely used than the South African Mining Industry Code of Practice (SAMI-COP). This will lead to harmonisation and consistency in exposure data interpretation across copper mines in the different countries.

Real-time monitoring

Instruments containing particle sensors were used in some studies to measure airborne dust concentrations. The main limitation with these instruments is the lack of documented literature on devices that measure the chemical composition of airborne dust. Even when used for RD monitoring, they need to be calibrated, as the material used in the factory calibration may have a different refractive index than the dust at the site, which reduces the accuracy of the instrument. The measured photometric-equivalent mass concentration is highly dependent on the refractive index of the material.[29] However, when calibrated on site, the sensors are invaluable as they provide exposure data in real- or near real-time that can be used for monitoring the efficacy of dust engineering controls.

Zambia should consider legislating the use of real-time airborne dust monitors for the purpose of evaluating the efficacy of dust controls. Respirable dust concentrations take days or more to be analysed by laboratories, while RD concentrations from real-time monitors are available much sooner (in real- or near real-time).

Health risks

Copper mines are not free of cases of silicosis. Several studies have documented the correlation of RCS exposure with the development of silicosis and other OLDs in copper mines. For example, in a study in China, Wang et al. (2020)[1] estimated the incidence of silicosis among copper mine workers as 2.5 per 1 000 person-years. In another study, international health and safety professionals investigated the conditions at an open-pit copper mine in Cananea, Mexico in 2007 and found that workers had the following symptoms: shortness of breath, wheezing, cough, and elevated sputum production.[6] They concluded that these symptoms might be related to dust exposure. A study in Chile monitored 5 939 workers exposed to silica dust and reported an incidence of silicosis of 2.85 per 1 000 miners.[30] This was lower than the incidence rate reported in the Democratic Republic of the Congo, viz. 10.8 per 1 000 miners in the period 1970 to 1995 at Lubumbashi Copper Mine.[8] In Zambia, for the years 2022 and 2023, 66 cases of pneumoconiosis were diagnosed in miners and ex-miners.[31] These studies clearly show that silicosis in copper mineworkers is a global challenge.

Additional recommendations for a dust monitoring programme for Zambia

This systematic review was motivated by Zambia's initiative to develop an occupational hygiene monitoring programme, initially centred on occupational exposure to airborne contaminants in copper mines. Zambia should base such a programme on best-practice sampling methods and technology. Zambia has not established OELs for RD and RCS.[23,31] We recommend that OELs be adopted from countries in Africa with similar socio-economic statuses, until such time as a country-specific OEL is agreed upon. Zambia should consider adopting an 8-hr TWA exposure limit of 0.05 mg/m^3, as countries with well-established exposure monitoring programmes such as the United States and Australia have legislated this limit, while South Africa is considering reducing to this limit. A more stringent exposure limit for RCS might need to be considered when socio-economic factors are taken into account.

There is a shortage of occupational hygienists in Zambia. Competent personnel should be trained and certified to increase the country's capacity to accurately measure RD and RCS exposure concentration, conduct risk assessments, and drive the implementation of control measures.

Limitations

Only articles published in English were included in the review. Those that reported RD and RCS exposure data from copper mines together with other commodities were not included. Both these criteria affected the number of articles included in the systematic review. The average percentage of RCS measured in the mines in the reviewed articles was calculated regardless of whether RCS content was measured from bulk, personal, or settled dust. Thus, the single value of the percentage of silica obtained in each study was an estimate of the RCS concentration that could potentially be in the breathing zone of a mineworker.

CONCLUSION

There is evidence in the literature of overexposure to RD and RCS in copper mines, globally. Zambia needs to develop an airborne dust and RCS monitoring programme for the copper mines, based on established standards and methods used in other countries. Occupational hygienists should be recruited and/or trained to help establish the programme and to implement and monitor it. In the interim, Zambia should consider adopting the NIOSH analytical methods for RD and RCS quantification; established standards such as the CEN standard (BS EN 689:2018) for assigning workers to SEGs and compliance testing; and 8-hr TWA exposure limits of 3 mg/m^3 and 0.05 mg/m^3 for RD and RCS, respectively.

KEY MESSAGES

1. There were relatively few studies in the open-access online literature that documented dust concentrations in copper mines.
2. Most studies on occupational exposure to airborne dust in copper mines have measured measured RD and not RCS.
3. Exposure to RD was better controlled than exposure to RCS in the studies included in the systematic review.
4. Most of the studies used NIOSH methods; 0600 for RD quantification, and 7500 or 7602 for RCS quantification.
5. All papers reported AMs of RCS personal exposure measurements that exceeded the ACGIH-TLV of 0.025 mg/m^3.

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DECLARATION

The authors declare that this is their own work; all the sources used in this paper have been duly acknowledged. The authors declare that no conflicts of interest exist.

AUTHOR CONTRIBUTIONS

Conception and design of the study: LN, MS, DM, PH, MDM, SJLL
Data acquisition: LN, PH, MDM, SJLL
Interpretation of the data: LN, MS, PH, MDM, SJLL
Data analysis: LN, MS, DM, PH, MDM, SJLL
Drafting of the paper: LN, PH, MDM, SJLL
Critical revision of the paper: LN, MS, DM, PH, MDM, SJLL

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