Respirable crystalline silica dust exposure and regulated occupational respiratory diseases in the Zambian copper mining sector: a review and recommendations

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ABSTRACT

Background: Exposure to respirable dust is widespread in the mining industry. One of the significant components in dust is respirable crystalline silica (RCS), which causes pulmonary silicosis; RCS exposure is also associated with tuberculosis. The health effects of exposure to RCS in Zambian copper miners are unclear.
Objectives: This review describes RCS exposure, associated occupational respiratory diseases, and existing dust exposure management programmes in the Zambian copper mining industry. Research gaps are also identified.
Methods: Online search engines (Google Scholar, PubMed, and Web of Science) were used to identify relevant published literature, and governmental databases and websites were searched for information.
Results: Only two studies have reported RCS dust exposure in the Zambian copper mining industry, and seven studies describe related diseases. The Zambian Ministry of Health reports on only two occupational respiratory diseases: silicosis and tuberculosis (TB). Zambia does not have an occupational health policy or programmes that protect workers in dusty operations from exposure to RCS.
Conclusion: Little is known about exposure to RCS and related occupational diseases in the Zambian copper mining industry. The absence of legislative guidelines for an RCS monitoring programme places copper miners at risk of developing respiratory diseases because of high and uncontrolled RCS levels. An RCS management programme should be developed and implemented to investigate the exposure of miners to RCS, and to promote the implementation of control measures.

INTRODUCTION

Mining activities involve extracting minerals from the earth's crust, during which workers are exposed to mineral dust,[1] including crystalline silica.[2] Exposure to respirable crystalline silica (RCS) causes pulmonary diseases such as silicosis, and is associated with chronic obstructive airways disease, tuberculosis (TB), and lung cancer.[3,4] Silicosis and the other pneumoconiosis are diseases associated with exposure to respirable mineral particles that damage the lungs. Respirable crystalline silica results in the formation of scar tissue that interferes with gas exchange.[3,5] Workers in dusty jobs such as drilling, crushing, tramming, and tipping are exposed to RCS and are, therefore, susceptible to developing silicosis. Unfortunately, most mine workers in southern Africa work in poorly controlled environments, where exposure to high levels of RCS increases their risks of developing silicosis and TB.[6]

Zambia is noted for its mineral wealth, particularly copper, and the mining industry contributes more than 50% of foreign earnings for the country.[7] More than 73 000 people are employed in the Zambian copper mining industry, making up 2.4% of the total workforce in the southern African extractive industry.[7]

Mining in Zambia

There are four underground copper mines in the Copperbelt province of Zambia, viz. Konkola Mine, Mufulira Mine, Nchanga Mine, and Nkana Mine, located in Chililabombwe, Mufulira, Chingola, and Kitwe districts, respectively. There are also four open-pit mines, namely, Lumwana, Kansanshi, and Kalumbila in the North-Western province and Nchanga Mine in the Copperbelt province. Even in open-pit mining, a substantial amount of dust is emitted during operations.[8] Miners working in dusty operations have been observed to work without respiratory protective equipment, which increases the risk of dust exposure.[9]

Crystalline silica exposure limits

Regulatory agencies in many countries have developed exposure limits to protect workers from the negative consequences of exposure to RCS. These limits specify the highest level of RCS to which employees may be exposed for a predetermined length of time (eight hours),[10] and range from 0.025–0.1 mg/m^3.[11–14] The health-based threshold limit value (TLV®), published by the American Conference of Governmental Industrial Hygienists (ACGIH), is 0.025 mg/m^3.[15] The USA's Occupational Safety and Health Administration (OSHA) enforces an RCS permissible exposure level (PEL) of 0.05 mg/m^3 for all mining and non-mining industries.[16]

Mining legislation in Zambia

Although there is a framework and guidance for creating an occupational health and safety department in Zambia, the Occupational Health and Safety Act of 2010 focuses on health and safety of workers.[17] The Zambian Mines and Minerals Development

Act of 2015 focuses on creating an occupational health and safety department in a workplace,[18] and there is no legislation for workplace air monitoring. The Zambian copper mining industry does not have a PEL, or any other limit, for RCS exposure. International mining companies in Zambia use the voluntary exposure limits of industrialised nations.

The objectives of conducting this review were to describe RCS exposure and related occupational respiratory diseases (silicosis, chronic obstructive diseases, TB, and lung cancer) in the Zambian copper mining industry, to describe existing dust exposure management progammes in the Zambian mining industry, and to identify research gaps.

METHODS

Data on miners' exposure to RCS are not readily available for the Zambian mining sector and it is not easy to access exposure data and job records from the mining houses. For this review, we searched Google Scholar, PubMed, and Web of Science. The search terms used were 'respirable crystalline silica exposure', 'occupational respiratory diseases', 'dust exposure management', 'monitoring programmes', 'Zambian mining industry', 'control of RCS exposure', 'regulated occupational diseases in Zambia', and 'control of occupational diseases in Zambia'. Articles from the databases were scrutinised for relevance, based on the aims of the published studies.

Second, official databases and websites, such as that of the Ministry of Health and the Ministry of Mines, were searched for information about miners' exposure to RCS and occupational diseases in the Zambian copper mines. The Ministry of Mines website was searched to learn more about RCS exposure in the Zambian mining industry because the Mine Safety Department (MSD) is responsible for all matters pertaining to safety and health of persons employed in exploration, mining, and mineral processing operations. The Occupational Health and Safety Institute (OHSI), a division of the Zambian Ministry of Health, keeps track of occupational illnesses by publishing information in the Ministry's yearly annual health statistical reports, which are available online. The annual reports for the years 2019 to 2021 were scrutinised for statistics on occupational diseases.

RESULTS

Only nine studies from the scientific literature met the inclusion criteria and provided information about RCS exposure and/or cases of occupational respiratory diseases within the Zambian copper mining industry (Table 1). None addressed the issue of health policies, RCS risk assessment implementation, or dust suppression methods.

Studies on RCS exposure measurements in Zambia

Only two papers focused on quantifying RCS exposure concentrations. Hayumbu et al. (2008)[19] reported respirable dust and RCS exposure among Zambian copper miners. Mean concentrations of total respirable dust were above 5 mg/m^3 at the two mining sites: 0–7.76 mg/m^3 and 0–6.94 mg/m^3, respectively. The mean RCS exposures were 0.143 mg/m^3 (0–1.30 mg/m^3) and 0.06 mg/m^3 (0–0.32 mg/m^3) at the two mines, respectively; these concentrations exceeded the OSHA PEL.[19] There were poor dust monitoring strategies at both mines, which prevented identification and control of high exposures that may increase risk of disease. The authors recommended establishing an accredited national respirable dust and RCS laboratory to provide effective monitoring, and implementing mine-dust control measures. The second study, published by Mchaina and Misra (1983),[20] investigated the relationship between dust exposure and the development of pneumoconiosis in two mines, more than 40 years ago. Total respirable dust ranged from 0.320 mg/m^3 to 2.43 mg/m^3 at the one mine, and from 0.505 mg/m^3 to 4.00 mg/m^3 at the other; the percentages of silica in the respirable dust samples were 31% and 41%, respectively. Using a cumulative dust exposure matrix, the authors calculated that the probability of contracting pneumoconiosis was 13%.

Studies on occupational respiratory diseases in Zambia

Three papers provided results from the analysis of health surveillance data from the OHSI,[21–23] concluding that there was an association between silicosis, TB, and exposure to respirable dust. Ngosa and Naidoo (2016)[21] reviewed the medical data of 357 in-service miners, and calculated a dose response risk for pulmonary tuberculosis (PTB) among underground copper miners exposed to RCS. The median RCS dust level was 0.3 mg/m^3; the overall prevalence of PTB was 9.5%. There was a significant association between RCS exposure and PTB (OR 6.4, 95% CI 1.8–23). The authors concluded that there was a significant increase in disease prevalence with cumulative respirable silica dust exposure ($p < 0.01$).

According to Mulenga et al. (2005),[22] occupational illnesses such as silicosis and TB have been recorded among workers in the Zambian copper mining industry since the early 1960s. They investigated silicosis and TB trends in Zambian copper mines before and after the onset of HIV/AIDS, and reported that, prior to the epidemic (1960–1970), the number of silicosis cases exceeded that of TB cases. The prevalence of silicosis decreased from 28.6% prior to the epidemic, to 12.4% in the period 1992–2002, but the prevalence of TB increased from 37.1% to 86.1%.

Dust exposure among Zambian miners has been associated with cases of occupational lung diseases and two studies have shown that underground miners are more susceptible to silicosis than open-pit miners. An analysis of mine worker medical records from January 2004 to December 2008, obtained from the OHSI database, compared silicosis in the underground and open-pit mines, where the proportions of silica in the rock being mined and in the airborne dust samples collected were similar. There were fewer silicosis cases in the open pit than in the underground mines (Figure 1(a)).[23] For each year spent working underground, miners were 14% more likely to develop silicosis than those involved at open-pit mining. This may be attributed to better natural ventilation in the open-pit mines.

A cross-sectional study conducted in 2019 on 168 mine workers at Konkola Mine in Chililabombwe, also showed that underground miners[24] were more likely to contract silicosis and other occupational diseases, such as TB, than those working in open-pit mines (Figure 1(b)). The prevalence of silicosis in underground miners was 38%; in open-pit miners, it was 10%. The predictors of silicosis were duration of employment, occupation, and work area.

Laima et al. (2012)[25] investigated lung function impairment among open-pit miners at Nchanga Mine in Chingola district. More than a quarter (27%) of the miners had lung impairments, of which 3.3% were severe, 4.0% were moderate, and 19.7% were mild. In a more recent study, Chanda-Kapata et al. (2016)[26] reviewed literature on the burden of TB in Zambian mines in order to guide focused interventions. The authors advised that dust control measures be strengthened through engineering controls and anti-smoking programmes. They concluded that there was not enough research in Zambia's mining sector to fully understand the burden of TB and other risks associated with dust exposure in the mining environment.

Mwaanga et al. (2019)[27] conducted research on the effects of air pollution from mining operations on human health, plants, animals, and infrastructure in the North-Western and Copperbelt provinces. They concluded that research should be conducted by interdisciplinary research groups in order to understand better the health effects of pollution from the mines.

Information from official databases and websites

The OHSI and Mine Safety Department did not have any documentation on RCS exposure in the Zambian copper mining industry. The annual health statistical reports from the Ministry of Health did not have statistics for occupational diseases, other than for TB where it was reported that there was a reduction in the prevalence from 49% in 2019 to 43% in 2021.[28] RCS exposure and occupational respiratory disease surveillance in Zambia is monitored by the OHSI of the Ministry of Health, but no statistics are reported.

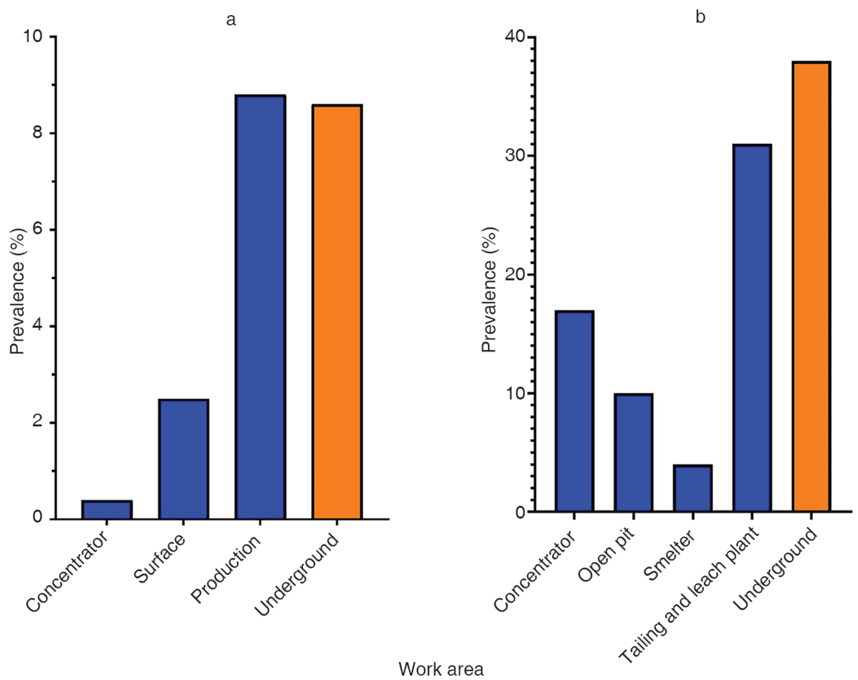
Programmes for controlling RCS exposure and occupational diseases in Zambia

The Zambian Occupational Health and Safety Act of 2010 focuses on the general welfare of workers in terms of health and safety, but there are no policies or programmes guiding employers on how to manage exposure to dust.[29]

The lack of a stringent system to protect miners exposed to RCS has also been observed in other southern African countries, with the exception of South Africa, which has a National Programme for the Elimination of Silicosis.[6] Brouwer and Rees[30] reviewed the silicosis elimination programme from the point of reducing exposure to RCS. They indicated that concentrations of exposure and the numbers of silicosis cases in mining and non-mining industries are decreasing.

Table 1. Studies on RCS exposure and occupational respiratory diseases in the Zambian copper mining industry

Authors, year	Topic	Measured exposure	Conducted health surveillance	Analysed health surveillance data	Reviewed literature
Hayumbu et al., 2008 [19]	RCS exposure	✓	-	-	-
Mchaina and Misra,1983[20]	RCS exposure, pneumoconiosis	✓	-	-	-
Ngosa and Naidoo, 2016[21]	Pulmonary tuberculosis	-	-	✓	-
Mulenga et al., 2005 [22]	Silicosis, tuberculosis	-	-	✓	-
Sitembo, 2012[23]	Silicosis	-	-	✓	-
Zimba et al., 2019[24]	Silicosis	-	-	-	✓
Laima et al., 2012[25]	Lung function impairment	-	✓	-	-
Chanda-Kapata et al., 2016[26]	Tuberculosis	-	-	-	✓
Mwaanga et al., 2019[27]	Mine air pollution	-	-	-	✓



(a) adapted from Sitembo (2012),[23] (b) adapted from Zimba et al. (2019)[24]
Data represent silicosis prevalence in different work areas from 2004 to 2008; surface and underground operations are represented by blue and orange bars, respectively

Figure 1. Prevalence of silicosis cases per work area as reported in two studies in the Zambian copper mining industry

The South African mining industry has also developed a code of practice (COP) for an occupational health programme on personal exposure to airborne pollutants from which other countries in the region can learn.[31] The COP highlights sampling strategies that should be implemented within a scheduled area. The steps for an occupational hygiene programme include:

1. Risk assessment, and identification of homogenous exposure groups
2. Sampling and analysis methodologies, which focus on quality control
3. Personal exposure monitoring of miners in dusty jobs
4. Integration of the hierarchy of control measures, starting with the most exposed workers in dusty work areas
5. Reporting and recording whether the workplace facility is fit for workers in terms of compliance with health and safety standards

Zambia and other countries in southern Africa can learn from South Africa's occupational health regulations and programmes: for example, the establishment of medical surveillance programmes, monitoring of dust concentrations in the work environment, and the introduction of controls to reduce dust levels. The focus should be on measuring respirable dust and RCS exposures for miners working in dusty areas.[31]

The non-existence of national monitoring programmes in Zambia is worrying. A similar COP to that in the South African mining industry should be replicated for countries in the region to guide hygienists on sampling dust concentrations and exposures. There is a need for Zambia to establish a dust measurement system, which should be ISO 175025-accredited (a standard for testing laboratories) to analyse dust samples for respirable dust and RCS.

The following are recommendations to improve the reporting of RCS exposure and occupational respiratory diseases in Zambia:

- Develop and implement a national programme to monitor closely the exposures of respirable dust and RCS, and occupational diseases
- Implement risk assessments in workplaces as a first step towards protecting workers from hazards
- Conduct empirical studies on respirable dust, RCS exposure, and associated diseases in mining (and non-mining sectors) involving dusty activities
- Establish effective control measures for respirable dust suppression in copper mining and other industries that involve respirable dust exposure
- Establish a national database for the reporting and comprehensive documentation of respirable dust and RCS exposure of workers in the country's mining and related industries
- Establish training programmes to educate miners on the risks associated with RCS exposure, including silicosis and TB
- Train workers on the use and management of PPE that can protect them from exposure to RCS until more effective control measures can be implemented
- Establish a national dust laboratory to provide effective dust control measures for miners

There is a need for more studies on RCS exposure in Zambia so that the Occupational Health and Safety Act of 2010 can be updated with guidelines on workplace air monitoring programmes. This will facilitate standardised monitoring in the mining sector. Currently, each mining house conducts sampling in accordance with its own standards and capacity.

CONCLUSION

Although Zambia has been mining copper for more than a century, remarkably little is known about the prevalence of silicosis and, specifically, the relationship between the length of RCS exposure and silicosis occurrence among mine workers. Only nine studies have investigated exposure to RCS and related occupational respiratory diseases in the Zambian copper mining industry in the last 40 years. Overall, the literature showed that workers in the copper mines in Zambia are exposed to high concentrations of RCS. There are no regulations and programmes governing RCS exposure in the Zambian copper mining industry, and only two occupational respiratory diseases (TB and silicosis) are reported. Tuberculosis is monitored and reported in the Ministry of Health's annual statistics. Silicosis is monitored by the OHSI under the Ministry of Health, but no statistics are currently reported. It is challenging to monitor RCS exposure in the mining industry due to the lack of legislation governing workplace air monitoring in the Zambian Occupational Health and Safety Act of 2010.[17] Therefore, data on RCS exposure concentrations are scarce, and only available from research that has been conducted in the mines.

The studies identified in the literature review do not provide a true reflection of the status of RCS exposure and respiratory diseases in the Zambian copper mining industry, and do not provide information about trends in the levels of RCS or the prevalence of diseases such as TB and silicosis. Zambia needs to create a standardised RCS monitoring programme to protect miners in the copper mining industry, by investigating exposure to RCS in dusty work areas. Considering that only TB has been the focus of occupational respiratory diseases in the mining industry,[29] there is a need for annual respirable dust and RCS monitoring programmes that can be used as motivation to strengthen the management of silicosis and other respiratory diseases. Recommendations from this review can be used as the first step in protecting workers from RCS dust exposure.

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KEY MESSAGES

1. There is limited scientific literature describing research that has been conducted on RCS exposure and occupational respiratory diseases in the Zambian copper mining industry.
2. There is a need to update the Zambian Occupational Health and Safety Act of 2010 on workplace air monitoring.
3. There is a need for Zambia to strengthen occupational health regulations regarding RCS exposure and monitoring programmes, in line with countries like South Africa.

DECLARATION

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

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AUTHOR CONTRIBUTIONS

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

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