Silicosis in Zambian ex-copper miners: A cross-sectional study

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Background. Dust exposure in copper mining, an important industry in Africa, poses a risk of silicosis and pulmonary tuberculosis (TB). Despite a number of reports on silicosis in Zambian copper miners since the 1960s, there has been no published report on silicosis prevalence.
Objectives. To determine the prevalence of silicosis and related radiological abnormalities in Zambian copper miners.
Methods. A cross-sectional analysis was conducted of 496 ex-copper miners' chest X-rays (CXRs) taken at the Occupational Health and Safety Institute in Kitwe, Zambia, between October 2019 and September 2020. Two experienced readers classified anonymised CXRs by consensus using the International Labour Organization (ILO) classification system for pneumoconiosis. The association between CXR outcomes and occupational variables, adjusting for age, was analysed using logistic regression.
Results. A total of 472 records were analysable. Of the miners, 82% were from seven companies across six mining districts, with most having worked in Kitwe and Chingola. Median service length was 25.4 years and median age 62.8 years. Silicosis of nodular profusion ≥ILO 1/0 was found in 8.3% (95% confidence interval (CI) 5.9 - 11.1), with ILO categories 1 and ≥2 comprising 4.9% and 3.4%, respectively. Silicotuberculosis was present in 4.0%. Exposure-response relationships between silicosis and occupational metrics were weak with wide CIs. Other CXR abnormalities were features suggestive of TB (16.5%; 95% CI 13.3 - 20.2) and cardiomegaly (19.3%; 95% CI 15.8 - 23.1). Adjusting for age, TB was strongly associated with silicosis (odds ratio (OR) 6.0; 95% CI 3.0 - 11.9) but unrelated to service length. Cardiomegaly was associated with service length after adjustment for age (OR 1.38; 95% CI 0.94 - 2.10).
Conclusion. The prevalence of silicosis in Zambian copper miners has not changed since the last (unpublished) study in 2012. Best-practice measurement of silica exposure in all copper mines and comprehensive surveillance of ex-miners for silicosis and TB are needed. The unexpected association of cardiomegaly with length of service warrants investigation of possible occupational risk.

Keywords: Silicosis, tuberculosis, cardiomegaly, copper mining, Zambia.

Afr J Thoracic Crit Care Med 2025;31(3):e2985. https://doi.org/10.7196/AJTCCM.2025.v31i3.2985

Study synopsis
What the study adds. Although there have been previous reports on silicosis in Zambia, this is the first study of the prevalence of silicosis published in the open literature. It shows a persistence since 2012 of silicosis prevalence among ex-copper miners of 8%, with a substantial proportion of radiologically advanced disease.
Implications of the findi gs. Zambia has a large and growing copper mining industry. Silicosis is a strong risk factor for pulmonary tuberculosis (TB), contributing to the elevated burden of TB among miners in Zambia. A multidisciplinary response of best-practice measurements of silica dust on all copper mines and countrywide medical surveillance of ex-miners for silicosis and TB is needed as a basis for primary prevention.

Copper mining, an important industry in Africa, poses a risk of silicosis and pulmonary tuberculosis (TB). Despite a number of reports on silicosis in Zambian copper miners since the 1960s, there has been no published report on silicosis prevalence.

Silicosis is a progressive, fibrotic pneumoconiosis resulting from inhalation of respirable crystalline silica. It is one of the oldest occupational lung diseases, yet it continues to cause significant morbidity and mortality in a number of silica-exposed workforces, notably among miners, including artisanal and small-scale miners, and in natural stone work, gemstone extraction and engineered stone fabrication.[1,2]

Zambia has been involved in mining for almost a century and is one of the world's largest producers of copper and cobalt. Mining is an important source of employment and government revenue. It includes both open-pit and underground operations. Dust characterisation and personal sampling on a few Zambian copper mines have shown a significant crystalline silica (quartz) content and concentrations of respirable silica above the US Occupational Safety and Health (OSHA) permissible exposure limit (PEL) of 0.05 mg/m^3.[3-6]

Annual incidence rates of silicosis and silicotuberculosis occurring in copper miners in Zambia are available from the 1950s,[7] but

without information on exposure duration. Counts of silicosis cases, also without exposure information or denominators, have also been published.[8] The only recent prevalence estimates, based on analysis of a national database of miner and ex-miner examinations, are from unpublished university dissertations.[9,10]

Silicosis, and independently exposure to silica dust, are strong risk factors for pulmonary TB, particularly in the context of congregate work settings and migrant labour in southern Africa.[11-13] Zambia is a high TB burden country, with the highest recorded population prevalence in Africa.[14,15] High prevalences of TB have been recorded in copper mining areas and among copper miners in Zambia.[4,14]

The purpose of the present study was to make use of the national database of miner examinations to publish an update of the prevalence of silicosis among copper miners in Zambia. It is also an opportunity to emphasise the importance of prevention of silicosis for the purpose of control of TB.

Methods

A descriptive cross-sectional study was undertaken to determine the prevalence of silicosis in ex-miners attending the Occupational Health and Safety Institute (OHSI), Kitwe, as part of routine surveillance. The OHSI's mandate is to conduct occupational medical examinations for all industries, including mining and ex-miners. The Institute has historically operated under different names, originally falling under the Ministry of Labour and Mines under Northern Rhodesia, after independence under the Ministry of Health, and currently under the Ministry of Labour and Social Security.

The study protocol was approved by the Zambian Tropical Diseases Research Centre Ethics Review Committee (ref. no. TRC/C4/04/2020) and the National Health Research Authority (ref. no. NHRA 00001/5/10/2020). The requisite permission and clearances were obtained from the director of the OHSI. All chest X-rays (CXRs) and data were anonymised and managed confidentially.

The data analysed were derived from existing surveillance of ex-miners. Both silicosis and TB in miners are compensable under Zambian legislation. All ex-miners in Zambia are mandated to undergo annual medical examinations, including CXR, in line with the Workers' Compensation Act No. 10 of 1999. These include ex-miners previously certified with TB, silicosis or both. All are assisted financially to attend the medical examinations.

The total number of ex-miners in Zambia is unknown and is the subject of a current Department of Labour investigation. During 2020, 3 890 examinations were carried out on ex-miners by the OHSI, with ~84% of these from copper mines. For this report, prevalence was derived from a sample of ex-copper miner CXRs and calculated as the proportion read with silicosis. Selection of CXRs was done by the OHSI to cover a period of a year, with the intention of selecting 50 CXRs by random sampling for each month. However, random sampling was not possible for technical reasons, and a convenience sample of 496 miners' readable CXRs was drawn. These had been taken at the OHSI during the period 10 October 2019 - 11 September 2020.

The CXRs were consensus read by two experienced pneumoconiosis readers using the International Labour Organization (ILO) classification.[16] Silicosis was defined radiologically as nodular profusion ≥1/0 on the ILO scale or as progressive massive fibrosis (PMF). These findings were digitally linked to the available sociodemographic data on the ex-miners.

The Medical Bureau Number was used as the unique identifier for each individual. The selection process ensured that there were no duplicates. The following data were extractable from the physical file on each subject and captured in Excel (Microsoft 365 Apps for Business; Microsoft, USA) and Stata 12 (StataCorp, USA): date of birth, gender, years of mining service, dates of first and last mining service, job type, geographical area of mine, commodity mined, and owner company. As years of exposure had not been captured as a routine, these were derived from the available start and end dates of the captured jobs. The data were analysed using Stata 12 (StataCorp, USA).

In defining TB and other radiological features on the posteroanterior CXR, related or unrelated to pneumoconiosis, the section on symbols from the ILO classification system was used. These symbols record additional radiographic features of importance in dust-exposed workers. Specifically, cardiomegaly (co) is defined as an abnormality of cardiac size (cardiothoracic ratio >50%) and/or shape. The symbol TB is interpreted as signs of TB compatible with active TB and/or post-TB lung disease, typically distinguished from silicosis by the finding of areas of asymmetrical opacity/opacities. Emphysema (em) is the symbol for findings of vertically elongated lungs (low-set and/or flattened diaphragms, and/or infracardiac air) and better understood as hyperinflation. Silicotuberculosis is the combination of silicosis and features suggestive of TB on the same CXR.

Using logistic regression, unadjusted and adjusted associations were measured between silicosis, TB and cardiomegaly and years of service and time since first exposure, adjusting for age. Associations are expressed as odds ratios (ORs) with 95% confidence intervals (CIs).

Results

A total of 496 CXRs were read. The median (interquartile range (IQR)) age of the ex-miners was 62.8 (57.1 - 67.6) years. There were two females and 333 unique recorded job titles in the group, with 82% coming from seven companies and the balance from another ~30 companies. These operate from six mining districts – Kitwe, Chingola, Mufulira, Luanshya, Chililabombwe and Kalulushi (Fig. 1). The commodity mined was copper, except in one case where it was recorded as copper/cobalt. A total of 84% of the miners had worked in Kitwe and Chingola. Median (IQR) length of service was 25.4 (20.4 - 30.4) years (range 1.7 - 42.3 years). The median (IQR) period since first exposure was 36.7 (31.8 - 45.4) years, with the year of first engagement ranging from 1966 to 2011. The median (IQR) period since last exposure was 12.0 (7.1 - 19.4) years.

The CXRs were read as ILO quality 1 or 2 (no technical defects, or any technical defects unlikely to impair interpretation) in 96.5%, and quality 3 (technical defects, but still interpretable) and 4 (unacceptable) in 3% and <1%, respectively. The prevalence findings are presented in Table 1.

Of the 496 CXRs, 472 were analysable; 22 could not be linked to a physical record with certainty, and 2 were test images.

Only 35.8% of the CXRs were normal. A total of 39 CXRs (8.3%) were read with silicosis, of which 16 (41.0% of the subtotal, and 3.4% overall) were read as ILO grade ≥2, i.e. advanced silicosis. One CXR with grade 3 profusion also showed PMF. The prevalence of 'sub-

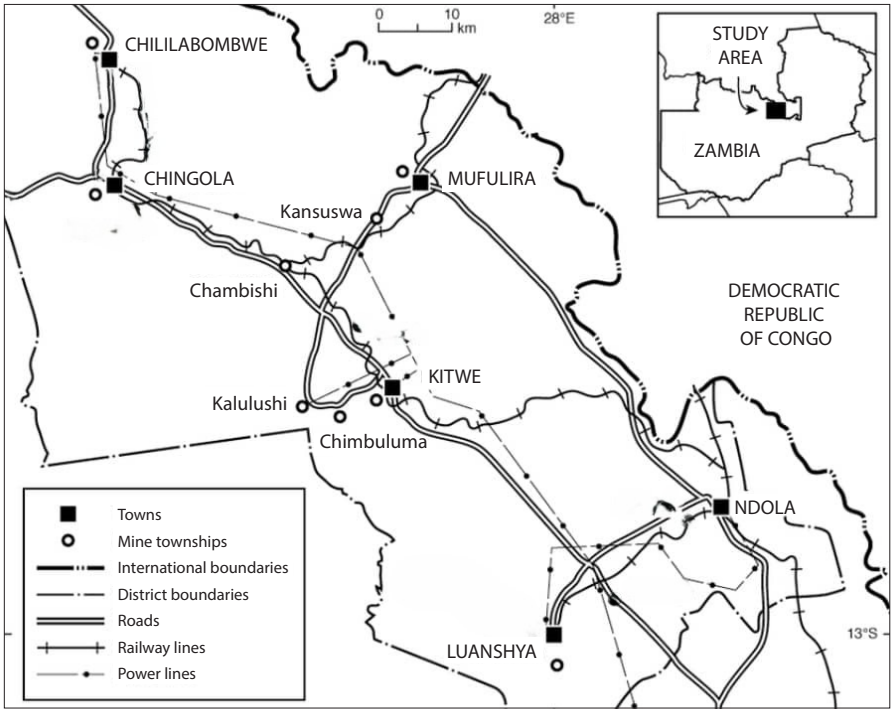

Fig. 1. Map of Copperbelt Province, Zambia, showing mining districts (reproduced with permission from the Occupational Health and Safety Institute, Kitwe, Zambia).

Table 1. Frequency of CXR findi gs in Zambian ex-copper miners (*N*=472)

CXR findi g	*n* (%)	95% CI
Any abnormality	303 (64.2)	59.7 - 68.5
Cardiomegaly	91 (19.3)	15.8 -23.1
Hyperinflation	87 (18.4)	15.0 - 22.2
Tuberculosis	78 (16.5)	13.3 - 20.2
Silicosis	39 (8.3)	5.9 - 11.1
ILO category 1	23 (4.9)	
ILO category 2	15 (3.2)	
ILO category 3	1 (0.2)	
Silicotuberculosis	19 (4.0)	2.4 - 6.2

CXR = chest X-ray; CI = confidence interval; ILO = International Labour Organization.

borderline' profusion, ILO category 0/1, was 5.1%.

The associations between silicosis and exposure variables are shown in Table 2, with ORs by 10-year strata. Also shown is the overall (average) across strata. None of the trends are monotonic and the 95% CIs are wide, almost all including the null value. The overall OR for years since first exposure is the exception, probably driven by the high OR of the last stratum. Adjustment for age did not change the results. In summary, no confident inferences could be drawn regarding trends with length of exposure.

TB on the CXR was strongly associated with silicosis (v. no silicosis): OR 6.0 (95% CI 3.0 - 11.9). This association did not change after adjusting for age. There was no relationship between TB and length of service or age (not shown). Cardiomegaly was positively related to years of exposure: OR for 10-year increments 1.38 (95% CI 0.94 - 2.10), adjusted for age.

Discussion

The previous efforts to record silicosis occurrence in Zambian copper miners are summarised in Table 3. All the data are derived from the same examination platform in ex-miners as represented by the present-day Institute, which operated under different names in the past.

A mid-century study[7] reported annual incidence (i.e. presumably newly diagnosed cases) of silicosis and silicotuberculosis over a 10-year period. The weighted annual average incidence can be calculated as 2.6%. Mulenga *et al.*[8] reported 542 cases of silicosis over the period 1945 - 2002. They showed a decline in the annual number of cases of silicosis and silicotuberculosis (out of all disease cases recorded in the database including tuberculosis) from 249 during the period 1960 - 1970 (mean 24.9 per year) to 160 during the period 1992 - 2002 (mean 8 per year).

The first silicosis prevalence study was of working miners over the period 2003 - 2004. Relatively low prevalences of silicosis were found, ranging from 0.8% to 2.2% across mines.[9] However, a subsequent study of ex-miners (2004 - 2008) recorded an overall silicosis prevalence of 8.8%.[10]

The demonstration of a silicosis prevalence of 8.3% in the present study (2019 - 2020) therefore indicates no change in silicosis prevalence among ex-miners during the past 12 - 16 years. However, the proportion of silicosis cases with advanced radiological profusion (≥ILO 2 or 3) of 41% in the present study is much lower than the 78% in the long-term series reported by Mulenga *et al.*[8]

English language (or translated) studies of silicosis prevalence among copper miners from other countries are few. Prevalences range from 1.2% among 2 500 copper miners in the Democratic Republic of the Congo[17] to 35% among 100 former copper miners in Brazil.[18] Without information on covariates such as mining methods, exposure time and participant selection, it is difficult to interpret these differences in relation to risk. The prevalences reported from the Zambian copper mines are also considerably lower than those found among active and former miners on the South African (SA) gold mines.[12]

TB in Zambia has been shown to have a strong relationship to mining activities. Zambia's first National TB Prevalence Survey (2013 - 2014) found a prevalence of active TB in adults >15 years of age of 638 per 100 000, with the highest prevalence in the Copperbelt Province (1 211 per 100 000).[14] The association was confirmed among copper miners, where a high prevalence of certified active TB of 9 500 per 100 000 was recorded for the period 2005 - 2010, 15 times that of the general population.[4]

Table 2. Association of silicosis with occupational exposure variables in Zambian ex-copper miners (*N*=472)

Interval of exposure	*n*/*N* (%)	OR (95% CI)	OR (95% CI) over all intervals of exposure
Years of exposure			
≤10	4/45 (8.9)	1	1.14 (0.79 - 1.64)
>10 - 20	8/95 (8.4)	0.94 (0.27 - 3.31)	
>20 - 30	12/204 (5.9)	0.64 (0.20 - 2.09)	
>30	15/128 (11.7)	1.36 (0.43 - 4.34)	
Years since first exposure			
≤20	3/34 (8.8)	1	1.51 (1.04 - 2.19)
>20 - 30	3/47 (6.4)	0.70 (0.13 - 3.72)	
>30 - 40	9/195 (4.6)	0.50 (0.13 - 1.95)	
>40 - 50	17/164 (10.4)	1.20 (0.33 - 4.33)	
>50	7/32 (21.9)	2.89 (0.68 - 12.4)	
Years since last exposure			
≤10	10/166 (6.0)	1	1.22 (0.78 - 1.90)
>10 - 20	21/210 (10.0)	1.73 (0.79 - 3.79)	
>20	8/96 (8.3)	1.42 (0.54 - 3.73)	

OR = odds ratio; CI = confidence interval.

Table 3. Zambian studies of silicosis

Period covered	Publication	*N* (service status)	Age (years)	Service (years)	Silicosis
1950 - 1959	Paul, 1961[7]	25 812 - 38 373 (in service)	-	-	Total (including silicotuberculosis) N=810 Weighted average annual incidence 2.6%
1945 - 2002	Mulenga et al., 1998[8]	-	-	-	Total N=542* ILO grade 1 n=119 (22%) ILO grade 2 or 3 n=423 (78%)
2003 - 2004	Mwansa, 2004[9]†	1 122 (in service)	-	-	Prevalence 0.8 - 2.2% across mines
2004 - 2008	Sitembo, 2012[10]†	476 (ex-miners)	56 (mean)	21 (median)	Prevalence 8.8% (≥ILO 1/0) (95% CI 6.27 - 11.8)
2019 - 2020	Present study	472 (ex-miners)	62.8 (median)	28 (median)	Prevalence 8.3% (≥ILO 1/0) (95% CI 5.9 - 11.1)

ILO = International Labour Organization; CI = confidence interval.
*22.7% of 2 114 cases (all diagnoses), 1945 - 2002.
†Unpublished master's dissertation.

While increasing TB prevalence in the region can be attributed to HIV infection, itself linked to labour migrancy, an association between TB and gold mining activity independent of HIV has been demonstrated in southern Africa.[19] Among copper miners, a strong specific trend relationship between TB and cumulative respirable silica exposure has been shown.[4] The same study reported on the analysis of >16 000 konimetric particle measurements (in million particles per cubic foot) on copper mines between 1990 and 2010.[4] A conversion factor to gravimetric units (mg/m^3) assigned to individual miners based on their occupation was used to calculate overall respirable silica exposure per mine. These were four to eight times the current OSHA PEL of 0.05 mg/m^3.[4]

Few studies using gravimetric techniques have been published from Zambian copper mines. A 2008 study based on personal sampling at two mines found mean respirable quartz concentrations above the OSHA PEL – 0.06 mg/m^3 and 0.14 mg/m^3, respectively – with quartz fractions in the dust of 13.6% and 17.5%.[3] A 2023 study at one copper mine measured a substantially lower mean respirable silica concentration of 0.026 mg/m^3 and a quartz fraction of 5.3%.[5] Ninety-five percent of the sampled concentrations were below the OSHA PEL. However, the variations in technique of dust sampling and quartz fraction calculation and the limited number of mines sampled in these studies preclude confident statements about trends in silica exposure in the Zambian copper industry over time.

There are no Zambian figures for prevalence of CXR abnormalities suggestive of active TB or post-TB chest disease with which to compare the 16.5% found in the present study. In a general population CXR survey in Kenya, the proportion of CXRs screened with TB abnormalities was

10%, falling to 6.4% after expert review of a sample.[20] The Zambian miner prevalence of 16.5% is considerably higher than those above, but lower than those found in random samples of migrant ex-gold miners in SA (33.3%) and Botswana (23.9%).[21]

The high prevalence of cardiomegaly of 19.3% on CXR is surprising in an ex-mineworker population, even given the median age of 62.9 years. However, it is comparable to CXR prevalences in three recent geographically related studies, one at a Zambian hospital research site (16.7%),[22] another at a peri-urban site in Blantyre, Malawi (20.7%),[23] and a third in a population survey in Kenya (23.1%).[20] While the populations and study designs are different, the underlying mechanisms may be similar, related to age and accompanying comorbidity such as hypertension.[22] In the present study, the finding of an association of cardiomegaly with years of service adjusted for age raises the question of an occupational association. We did not have sufficient data to examine this issue further.

Study limitations

A limitation of this study is that prevalence is derived from a statutory medical examination database with the total number of examinations as the denominator. The representativeness of the sample for the population of ex-miners at risk is not known, but there are considerations that suggest selection bias including loss to observation of more advanced silicosis. These include the lack of an association between length of service and silicosis, and the legal requirement that miners with advanced silicosis cease exposure, returning to their homes in different parts of the country, some far from the Centre. The decline over time in the proportion of CXRs with advanced profusion could be a true decline in underlying severity, but could also be due to selection bias. To this source of bias could be added survivor bias, particularly with regard to silicotuberculosis, which is strongly associated with increased mortality.[24] The calculated prevalence figures for silicosis in ex-miners and the proportion of advanced disease may therefore be underestimates.

Another limitation is that in the absence of accurate measurements of respirable silica exposure, duration of employment is a limited surrogate for cumulative dust exposure.[25] This misclassification would result in attenuation of observed exposure-response associations.

Conclusion

This study has confirmed that silicosis remains a prevalent disease in Zambian ex-copper miners, with no apparent decline in overall prevalence shown since a comparable but unpublished study in 2012. Silica exposure has been confirmed to be a strong risk factor for pulmonary TB in Zambian copper miners and is likely to contribute to the high TB prevalences in copper mining populations in Zambia.

The findings have implications for medical surveillance of miners for silicosis and TB and prevention of both diseases through silica dust control. These involve a number of steps that reflect those set out in a recently published comprehensive operational plan for control of TB and silicosis in mining in southern Africa.[26] The occupational health and safety laws in Zambia need to be aligned with best practice in silica dust control. This process requires an awareness at the political and operational level of the risk of silicosis and TB. A legal occupational exposure limit is needed, drawn initially from that in use in the region in similar environments.

For effective management of occupational health and hygiene programmes, the legal framework further requires the building of human occupational health and safety capacity in enforcement agencies and mining sectors, both formal and informal. Establishing the current risk of silicosis and TB in the copper mining industry is a priority. It requires independent measurement of silica concentrations and quartz fractions at all mines, and fuller medical surveillance coverage of both miners and ex-miners.

Data availability. None.

Declaration. None.

Acknowledgements. The project was managed through the Aurum Institute, Johannesburg, by Bandile Mathandela, and previously by Andrew Titterton, who also co-authored the first protocol. This built on the terms of reference document received from the OHSI, Zambia.

Author contributions. Study conception: KN, MC; study design: JMtWN; manuscript draft: JMtWN, RE. All authors contributed to and approved the final version.

Funding. OHSI, Kitwe, Zambia.

Confl cts of interest. RE has written expert reports for plaintiff attorneys in silicosis litigation.

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Received 23 October 2024. Accepted 6 June 2025. Published 2 September 2025.