Annals of Work Exposures and Health, 2024, **XX**, 1–7
https://doi.org/10.1093/annweh/wxae060
Advance access publication 15 July 2024
Original Article

BOHS British Occupational Hygiene Society — The Chartered Society for Worker Health Protection

OXFORD

Feasibility of respirable crystalline silica exposure reduction in small-scale tanzanite mining in Tanzania

Manti Michael Nota[1,*], Stephen E. Mbuligwe[1], Gabriel R. Kassenga[1], Perry Gottesfeld[2]

[1]School of Engineering and Environmental Studies (SEES), Ardhi University, P. O. Box 35176, Dar es Salaam, Tanzania
[2]Occupational Knowledge International, San Francisco, CA, United States

[*]Corresponding author: Email: manti@okinternational.org

Abstract

Introduction: Respirable crystalline silica (RCS) exposures in tanzanite gem mining have been linked to tuberculosis and silicosis among miners. We conducted a plot study to assess RCS exposures and to introduce safer mining practices in one small-scale underground tanzanite mine.

Materials and methods: Personal and area air samples for RCS were collected during tanzanite mining operations before and after improved work practices employed to reduce exposures and analyzed using X-ray diffraction. Area samples were collected at the rest area, located approximately 300 m underground and 100 m from other work activities. Improved practices included the use of wet drilling methods and drilling with new bits.

Results: A total of 33 personal and 4 area air samples were collected. Pre-intervention, mean exposures for all operations, drilling operations, non-drilling activities, and area samples were 122 mg/m^3, 247 mg/m^3, 34.3 mg/m^3, and 1.95 mg/m^3, respectively which exceeded the U.S. OSHA Permissible Exposure Limit (PEL) by 2,440 times for all operations, by 4,946 times for drilling operations, by 686 times for non-drilling activities and 39 times for area samples collected at an underground rest area. The post-intervention results showed a 99% reduction of RCS exposures for wet drilling operations, 98.5% reduction for non-drilling activities, and 36% reduction for area samples. Despite improvements, post-intervention RCS exposures during drilling had a mean of 2.08 mg/m^3 or more than 41 times the OSHA PEL.

Conclusions: We successfully piloted a program to work with small-scale tanzanite miners to reduce RCS exposures and raise awareness about the occupational health risks of RCS, though additional measures are recommended to further reduce RCS exposures. Similar programs should be taken to scale throughout underground mining sites in Tanzania and other countries.

Key words: respirable crystalline siica; safer mining practices; small-scale mining; Tanzania; tanzanite; wet drilling.

What's Important About This Paper?

This study reports a pilot program involving wet drilling methods and new drilling bits that successfully reduced exposures to respirable crystalline silica in small-scale Tanzanite mining in Tanzania. The research demonstrates that silica exposure in small-scale mining is significant but can be reduced through sustainable workplace interventions within vulnerable communities.

Introduction

Mining in Tanzania in the modern era dates back over one hundred years under German colonial rule, during the First World War (Howard 2011). After the end of the war, control of Tanganyika area was ceded to the British, under whose colonial authority mining activities expanded. Mining focused on gold, diamonds, and a variety of coloured gemstones, until the discovery of tanzanite gems in late 1960s opened up a new opportunity in Northern Tanzania. Presently,

Received: March 1, 2024. Accepted: June 28, 2024.

tanzanite mining remains an important economic force in Tanzania. The Merelani Hills in the Simanjiro Manyara Region is the only place where tanzanite is found in commercial quantities (Howard 2011).

A major occupational health hazard associated with mining is exposure to RCS which is known to cause silicosis, cancer, and other disease (NIOSH 2002; Gottesfeld et al. 2015). Recent studies from Malawi, Ghana, and Zimbabwe have demonstrated significantly greater TB incidence rates among miners than the general population and greater risks for pulmonary TB among informal miners than those employed in industrial mining (Rambiki et al. 2020; Ohene et al. 2021; Moyo et al. 2022). Informal miners in Malawi exhibit a 50% higher likelihood of TB compared to those in formal sector mining (Rambiki et al. 2020). TB is also the leading cause of death among people with HIV highlighting the importance of controlling RCS exposures in countries with a high HIV prevalence (WHO 2023).

A recently published review article covering 18 studies that included 29,562 artisanal and small-scale miners from 10 countries showed that silicosis prevalence ranged from 11% to 37% (Howlett et al. 2023). The authors identified 8 studies that included air sampling results demonstrating high levels of RCS ranging from 0.19 to 89.5 mg/m^3 (Howlett et al. 2023).

Miners with active TB also contribute to secondary TB infections in the general population due to migration and therefore have a much greater impact than their numbers alone suggest (Rees et al. 2010). Apart from working with silica dust exposures in poorly ventilated areas, mining sites in Tanzania serve to increase community TB transmission in lower burden settings as workers with active TB return home (Mpagama et al. 2015). Miners in Tanzania also account for a significant percentage of TB patients who are later admitted for retreatment putting an extra burden on health systems (Mpagama et al. 2015).

Crystalline silica in the form of quartz is the most common component of soil and rock. Exposures to RCS from large-scale gold mining operations have been well documented in the past (Churchyard et al. 2004; Verma et al. 2014). A small number of studies have measured RCS in artisanal, small-scale mining (Gottesfeld et al. 2019; Mbuya et al. 2023). However, we are unaware of any publication measuring task-specific exposures or studies demonstrating the efficacy of silica reduction efforts in small-scale tanzanite mining.

Tanzanite miners typically use pneumatic jackleg drills from a compressors powered with electricity at the surface while working in underground mines. The jacklegs are used to loosen and remove waste rock and ore, which are then gathered in bags and brought to the surface using a manual or powered winch. On the surface mine tailings are transported to the waste storage areas. RCS dust is released into the air when miners drill, remove, and transport large quantities of rock in the effort to extract gemstone.

While attention is paid to reducing RCS exposures in industrial mines in Tanzania, the Ministry of Minerals has taken a number of steps to help formalize artisanal and small-scale mining. These programs include establishing specific zones for ASM, simplifying licensing procedures, and implementing training programs Despite these efforts, there has been little change and artisanal and small-scale mining continues without regard to health and safety considerations (Gottesfeld et al. 2015; Mutagwaba et al. 2018). Almost all tanzanite mines operate with informal labor arrangements.

This study was conducted to assess RCS exposures and to pilot safer mining practices including dust controls in one underground tanzanite mine. Because small-scale tanzanite miners lack basic personal protective equipment and generally operate equipment without dust controls in locations without ventilation, it is important to assess these exposures to better understand potential interventions, their limitations, and resulting risks for silicosis and TB.

Materials and methods

The mine owners cooperated in agreeing to the project plan and by asking miners to participate in training programs and assessments. In addition, the owners organized all the necessary support required during site monitoring and invested in capital improvements to introduce wet drilling.

An initial walkthrough survey was done in the underground tanzanite mine at approximately 400 m depth to evaluate the equipment employed, characterize similar exposure groups, and to gain a better understanding of work practices related to RCS exposures. We joined the mine supervisor in our initial visit to the underground mine to observe work practices and speak with the more experienced miners. After assessing the mine site, we conducted a meeting with owner's representative and miners to inform them about the visit, observations, and plans to conduct the air monitoring to implement site improvements.

We then conducted a 4-h training session with the miners to explain the hazards of RCS exposures and plans to implement dust controls to minimize exposures to protect workers. The training topics included sources of RCS, mining practices and behaviors contributing to RCS, health effects of RCS exposure (e.g. silicosis, TB, risks with HIV-positive miners, and lung cancer), and dust control measures. Furthermore, the training covered how to put on and handle the air sampling equipment.

Sample collection

Personal and area sampling for RCS was conducted during representative mining activities. Work tasks were divided so as to include personal samples for miners drilling, charging and blasting, waste rock bagging, and the manual movement of ore and tailings. All described operations were carried out by miners within 5 to 30 m from each other. In addition, a personal sample was used to assess the mine supervisor's exposure during the walkthrough survey and area monitors were set up in an underground rest area. Surface level activities that were monitored included the unpacking of waste rock bags into the truck.

The initial assessment was conducted in September 2022, after the workers training session but before the introduction of wet practices. In January 2023, additional air quality monitoring was conducted after the introduction of semi-wet and wet mining practices. During the second assessment, we also measured RCS concentrations during drilling with new drill bits as recommended after the initial air sampling assessment.

A total of 37 (33 personal and 4 area) air samples were collected for RCS. A total of 19 samples were initially collected while workers used dry work practices and standard drilling equipment. Dry methods included pneumatic drilling, rock bagging, handling, and transport under dry conditions. An additional 18 samples were collected during the post-intervention phase, including 12 samples when workers used semi-wet practices and 6 when workers used wet practices. Semi-wet practices refer to the event that miners *started* using a wet pneumatic drill, but the drill experienced a loss of water and compressed air to the extent that the drilling machine could not push out the mud and continue to drill. After experiencing these mechanical issues, the miners continued drilling under dry condition for the duration of the sampling period. Wet practices included wet pneumatic drilling and continual ore wetting during drilling, blasting and non-drilling activities.

RCS samples were collected using battery operated SKC Aircheck Model 224-PCXR4 air sampling pumps, SKC aluminum cyclones (SKC No. 225-01-02), tygon tubes, and 37-mm polyvinyl chloride (PVC, 5 µm pore size) filter cassettes as per NIOSH Method 7500 requirements. The air sampling pumps were calibrated using primary standard flow meter (Mesa Labs Biodefender 510) and set at the flow rate of 2.5 L/min before sampling. At the end of the sampling period, a post calibration check was done to measure flow rates for each pump. There was no deviation of more than ±5% in flow rates observed. For personal samples, the cassette was clipped to the workers lapel area in a vertically downward position. All personal samples reflect full shift (124 to 504 min) except the mine supervisor who was only monitored for a portion of his work day when he was underground (61 to 64 min). Each miner conducted a specific task for their full shift of variable length. Stationary area air samples were collected at the rest area located approximately 300 m depth underground, 100 m from other work activities. Samplers operated for the duration of the work shift. A field blank was collected on each of the monitoring days as per NIOSH Method 7500 requirements.

Samples were sent to Bureau Veritas (Novi, Michigan), an American Industrial Hygiene Association accredited laboratory for the analysis of crystalline silica using NIOSH Method 7500 with X-ray diffraction. Results were reported in mg/m^3. The limit of detection for the analysis was reported as 0.005 mg/filter. IHSTAT™ software was used for the statistical assessment.

Results

Table 1 summarizes the mean exposure for 17 personal samples measured underground before the introduction of improved work practices. The mean exposure was 122 mg/m^3 which exceeds the U.S. OSHA PEL by 2,440 times. The results show that all personal samples were above the PEL for RCS of 0.05 mg/m^3. The maximum RCS measured was 370 mg/m^3 from pneumatic drilling, which is 7,400-fold higher than the PEL. On the surface, the dumper operator had an exposure 0.18 mg/m^3 or 3.6-fold higher than the PEL.

The pre-intervention mean personal exposure for underground drilling operations was 247 mg/m^3 (range from 194 to 288 mg/m^3), and the mean for all non-drilling operational activities was 34.3 mg/m^3 (range 10.7 to 79.7 mg/m^3). The mean of the non-operational area samples in the underground rest area was 1.95 mg/m^3.

Table 2 provides results for 16 post-intervention samples (11 semi-wet and 5 wet) for underground mining operations. The overall mean was 9.01 mg/m^3, which is 180-fold higher than the PEL. Figure 1 shows the exposure reductions post-intervention with a mean RCS level for semi-wet drilling of 16.4 mg/m^3, which is 93% lower than pre-intervention and a mean of 2.08 for wet drilling which is 99% lower than pre-intervention.

The mean RCS level for semi-wet non-drilling activities was 2.51 mg/m^3 (range from 7.59 mg/m^3 to 19.42 mg/m^3) which is 50.2-fold higher than the PEL and was 0.50 mg/m^3 (range from 1.07 mg/m^3 and 2.37 mg/m^3) for wet non-drilling activities which is 10-fold higher than the PEL. Area samples at the rest area post-intervention for RCS was 0.3 mg/m^3, which is 6 times higher than the PEL.

Table 1. Pre-intervention personal exposure levels of respirable crystalline silica (RCS).

Sample number	Job type/Work activity	Sampling duration (min)	RCS (mg/m^3)	Ratio RCS/PEL
MS 5	Underground rock pneumatic drilling	240	370	7,400
MS 4	Underground rock pneumatic drilling	240	300	6,000
MS 3	Underground rock pneumatic drilling	300	210	4,200
MS 1	Underground blasting and manual transportation of rock bags	343	29	580
MS 8	Underground manual transportation rock bags	185	36	720
MS 10	Underground manual waste rock bags packing	185	14	280
MS 11	Underground rock pneumatic drilling and manual transportation rock bags	320	270	5400
MS 2	Underground rock pneumatic drilling	380	270	5,400
MS 12	Surface dumper operator (3trips)	139	0.18	3.6
MS 13	Underground manual waste rock bag packing	321	220	4,400
MS 14	Surface unpacking waste rock bag dumper	202	1.5	30
MS 15	Underground rock pneumatic drilling and manual transportation bags	336	260	5,200
MS 16	Underground manual waste rock bag packing	124	5.2	104
MS 17	Underground rock pneumatic drilling and manual transportation rock bags	352	51	1,020
MS 20	Underground walkthrough survey (site supervisor)	61	1	20
MS 19	Underground blasting	285	31	620
MS 18	Underground manual transportation rock bags	331	5.1	102
		Mean	**122**	**2,440**

Discussion

This study highlighted that both pneumatic drilling and non-drilling activities in tanzanite underground mining exposed miners to RCS levels surpassing the U.S. OSHA PEL by 4946-fold and 686-fold, respectively, and the exposures were particularly elevated when employing dry methods (Tables 1 and 2).

Previous research in the Shinyanga region of Tanzania indicated that average airborne exposures during pneumatic drilling among informal underground gold miners were 337 times the current U.S. OSHA PEL for RCS (Gottesfeld et al. 2015). These exposures raise concern for possible acute silicosis among miners and can contribute to TB risk among miners (Gottesfeld et al. 2015).

In addition, our study revealed that introduction of wet methods and use of a new drilling bits showed an overall 99% reduction in RCS exposures for all underground mining operations compared with pre-intervention levels. Moreover, semi-wet methods operations reduced RCS exposures by 90%. RCS concentrations were also reduced in the rest area by 36% after the intervention. The reduction in exposures observed in this study are greater than seen in other intervention research. For example, a study done among artisanal gold miners in Nigeria revealed that introducing wet methods reduced RCS by 80% (Gottesfeld et al. 2019).

The study indicated a shared interest and motivation among both mining owners and miners to mitigate exposure to RCS and alleviate associated health risks. Mine owners actively participated in the study by introducing wet pneumatic drills, acquiring new drilling bits, and installing water pipes and storage tanks. Miners willingly underwent training, adopted wet methods, and carried sampling equipment as part of these efforts.

Table 2. Post-intervention underground personal exposure levels of respirable crystalline silica (RCS).

Sample number	Job type/work activity	Sampling duration (min)	RCS (mg/m^3)	Ratio RCS/PEL
03	Semi-wet rock pneumatic drilling and manual transportation rock bags	492	50	1,000
02	Semi-wet rock pneumatic drilling and manual transportation rock bags	376	18	360
07	Semi-wet rock pneumatic drilling, charging and blasting	480	3.1	62
04	Semi-wet rock pneumatic drilling and manual transportation rock bags	476	12	240
06	Semi-wet rock pneumatic drilling	480	15	300
09	Wet rock pneumatic drilling and manual transportation rock bags	494	0.96	19.2
12	Wet manual waste rock bags packing	478	0.37	7.4
13	Wet manual transportation rock bags	429	0.32	6.4
11	Wet manual transportation rock bags	504	0.8	16
10	Wet rock pneumatic drilling	504	3.2	64
14	Semi-wet rock pneumatic drilling	362	14	280
15	Semi-wet rock pneumatic drilling and manual transportation rock bags	364	14	280
16	Semi-wet manual waste rock bags packing	367	2.8	56
17	Semi-wet charging and blasting	347	4.4	88
18	Semi-wet walkthrough survey	64	0.33	6.6
19	Semi-Wet rock pneumatic drilling	362	4.8	96
		Mean	**9.01**	**180**

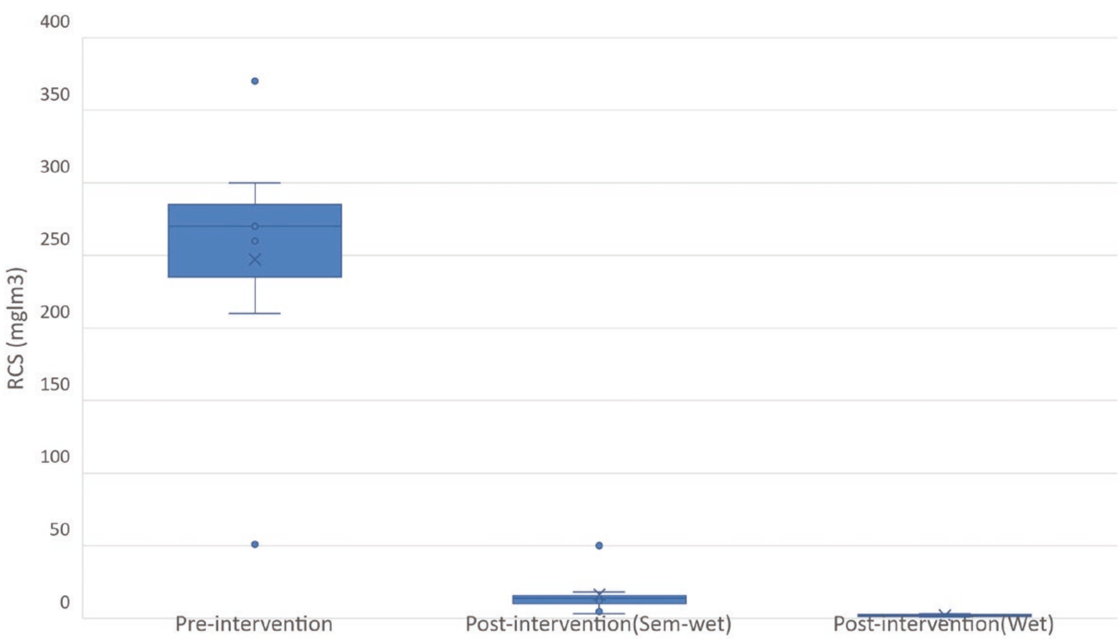

Fig. 1. Mean RCS personal exposure (mg/m^3) for all underground drilling activities pre and post-intervention.

Our study assessed RCS exposure according to different specific activities and revealed that drillers were exposed to higher levels of RCS compared to other tasks. No other studies were found that specifically evaluated RCS exposure for specific activities in tanzanite mining. The task-specific exposures noted in our study were considerably higher than the results from tanzanite mining reported by Mbuya et al. (2023). However, the median level reported of 1.23 mg/m^3 from Mbuya et al. (2023) study was similar to our median pre-intervention area air sample results. Their study did not record work assignments or activities for the workers that were monitored which may explain the discrepancy in measured RCS. In addition, whereas the present study analyzed silica content using NIOSH method 7500 with X-ray diffraction, Mbuya et al. (2023) relied on infrared absorption spectrophotometry with NIOSH method 7602. In comparing these analytical methods, XRD is considered a significantly more robust technique to analyze workplace samples due to less interferences from the common matrixes with the exception of high iron loaded samples (Akemi et al. 2022). Furthermore, XRD is able to more accurately analyze samples with much higher loading (Akemi et al. 2022).

Laboratory studies in the United States demonstrated that the use of sharp (new) drilling bits and substituting pneumatic drilling with electric drilling reduces exposures to RCS during concrete drilling. The study published in 2017 showed that the sharp bits reduced the mean RCS from 0.74 to 0.41mg/m^3 for a first sample and 0.89 to 0.41 mg/m^3 for the second sample (Carty et al. 2017). Another laboratory study comparing RCS exposures during concrete drilling using pneumatic and electric rotary hammer drilling found that mean RCS was 22.23 mg/m^3 with pneumatic drilling and 0.55 mg/m^3 with electric drilling (David et al. 2019).

A study summarizing data from formal sector metal and nonmetal miners in the United States from 2000 to 2019 showed that overall RCS exposures for surface and underground miners had a mean RCS exposure of 47.8 µg/m^3 and Geometric Mean (GM) exposure of 28.9 µg/m^3 (Misra et al. 2023) In contrast, our study of informal tanzanite miners had a mean pre-intervention RCS exposure of 122 mg/m^3 or more than 2,550-fold greater than formal sector miners in the United States.

Silicosis is normally not apparent until 20 yr or more after the first exposure to RCS. However, exposure to extremely high concentrations of RCS as observed with underground pneumatic drilling, are associated with an acute or accelerated form of silicosis that can occur within 1 to 3 yr (Akgun et al. 2006). Accelerated silicosis has been reported among gold miners in China, Scottish-stonemasons, and those installing engineered stone countertops (Akgun et al. 2006). In addition, silica exposed miners have up to 4 times greater risk of acquiring active TB (Ehrlich 2021).

Conclusions and recommendations

This first effort to pilot improved methods indicates that greater investment is needed to protect tanzanite miners. Although we were able to demonstrate the feasibility of sizeable exposure reductions with low-cost methods, more can be done to further reduce RCS levels as recommended below.

Mean exposure from non-drilling activities remained at more than 9-fold greater than the PEL implying that there is an urgent need to continue to improve work practices and drilling equipment to further reduce these hazardous conditions for protection of health of miners. As noted, mine owners should switch from pneumatic drills to electric drills for further reduction of RCS. It is also important that mine owners switch to wet core drills that inject water and bring the wet pulverized material out of the cut. Maintaining and replacing drill bits to keep them sharp will RCS exposures among miners as normally dull drill bits are associated with higher levels of RCS and noise. Another simple measure to reduce exposures is to increase waiting periods before reentering work areas after blasting rock to allow the dust to settle. Improved ventilation can also be used to move dust away from workers with the exhaust air going outside the work area.

Finally, along with these improved work practices, mine owners should assign appropriate respirators to all miners based on the observed RCS exposures. Based on our results for post-intervention underground drilling, full-face air-purifying respirator would be the minimum needed for this task unless additional reductions are achieved with improved ventilation and/or better drilling equipment. All miners assigned respirators should participate in an annual medical surveillance program, be fit tested, and attend training sessions on how to use and maintain respirators. All miners need training to become aware of the hazards from RCS in mining and the methods to reduce exposures.

We successfully piloted a program to work with small-scale tanzanite miners to reduce RCS and raise awareness of occupational health risks. Similar programs should be taken to scale throughout underground mining sites in Tanzania and other countries.

Acknowledgments

The authors acknowledge support for air sampling provided by Gem Legacy Inc. We would also like to thank Bureau Veritas, USA (Novi, Michigan) for generously donating air sample analysis.

Funding

Direct financial support for this project was provided by Gem Legacy.

Conflict of interest

The authors declare no conflict of interest relating to the material presented in this article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

Data availability

The sampling results are available by contacting the author.

References

Akemi I, Volpato J, O'Donnell GE, Mazereeuw M. Comparison of the analysis of respirable crystalline silica in workplace air by direct-on-filter methods using X-ray diffraction and fourier transform infrared spectroscopy. Ann. Work Expo. Health. 2022:66(5):632–643. https://doi.org/10.1093/annweh/wxab094

Akgun M, Mirici A, Ucar EY, Kantarci M, Araz O, Gorguner M. Silicosis in Turkish denim sandblasters. Occup. Med. 2006:56(8):554–558. https://doi.org/10.1093/occmed/kql094

Carty, Paul & Cooper, Michael & Barr, Alan & Neitzel, Richard & Balmes, John & Rempel, David. The effects of bit wear on respirable silica dust, noise and productivity: a hammer drill bench study. Ann. Work Expo. Health. 2017:61(6):1. https://doi.org/10.1093/annweh/wxx041

Churchyard GJ, Ehrlich R, WaterNaude J, Pemba L, Dekker K, Vermeijs M, White N, Myers J. Silicosis prevalence and exposure-response relations in South African goldminers. Occup Environ Med. 2004:61(10):811–816. https://doi.org/10.1136/oem.2003.010967

David R, Antonucci A, Barr A, Cooper MR, Martin B, Neitze RL. Pneumatic rock drill vs. electric rotary hammer drill: productivity, vibration, dust, and noise when drilling into concrete. Appl Ergon. 2019:74:31–36. https://doi.org/10.1016/j.apergo.2018.08.005. ISSN: 0003-6870.

Ehrlich R, Akugizibwe P, Siegfried N, Rees D. Silica exposure, silicosis and tuberculosis – a systematic review. BMC Public Health. 2021:21(1):953. https://doi.org/10.1186/s12889-021-10711-1

Gottesfeld P, Andrew D, Dalhoff J. Silica exposures in artisanal small-scale gold mining in Tanzania and implications for tuberculosis prevention. J Occup Environ Hyg. 2015:12(9):647–653. https://doi.org/10.1080/15459624.2015.1029617

Gottesfeld P, Tirima S, Anka SM, Fotso A, Nota MM. Reducing lead and silica dust exposures in small-scale mining in northern Nigeria. Ann. Work Expo. Health. 2019:63(1):1–8. https://doi.org/10.1093/annweh/wxy095

Howard AE. A Brief Introduction to the Geology and Mining Industry of Tanzania. Toronto, Ontario: SIKA Resources Inc; 2011.

Howlett P, Mousa H, Said B, Mbuya A, Kon OM, Mpagama S, Feary J. Silicosis, tuberculosis and silica exposure among artisanal and small-scale miners: a systematic review and modelling paper. PLOS Global Public Health. 2023:3(9):e0002085. https://doi.org/10.1371/journal.pgph.0002085

Mbuya AW, Mboya IB, Semvua HH, Msuya SE, Howlett PJ, Mamuya SH. Concentrations of respirable crystalline silica and radon among tanzanite mining communities in Mererani, Tanzania. Ann Work Expo Health. 2023:68(1):48–57. https://doi.org/10.1093/annweh/wxad062

Misra S, Sussell AL, Wilson SE, Poplin GS. Occupational exposure to respirable crystalline silica among US metal and nonmetal miners, 2000-2019. Am J Ind Med. 2023:66(3):199–212. https://doi.org/10.1002/ajim.23451

Moyo D, Ncube R, Kavenga F, Chikwava L, Mapuranga T, Chiboyiwa N, Timire C. The triple burden of tuberculosis, human immunodeficiency virus and silicosis among artisanal and small-scale miners in zimbabwe. Int J Environ Res Public Health. 2022:19(21):13822. https://doi.org/10.3390/ijerph192113822

Mpagama SG, Lekule IA, Mbuya AW, Kisonga RM, Heysell SK. The influence of mining and human immunodeficiency virus infection among patients admitted for retreatment of tuberculosis in Northern Tanzania. Am J Trop Med Hyg. 2015:93(2):212–215. https://doi.org/10.4269/ajtmh.15-0189

Mutagwaba, W, Bosco Tindyebwa, J, Makanta, V, Kaballega, D and Maeda, G (2018) Artisanal and small-scale mining in Tanzania – Evidence to inform an 'action dialogue'. Research report, IIED, London. http://pubs.iied.org/16641IIED ISBN: 978-1-78431-594-8

NIOSH (National Institute for Occupational Safety and Health). (2002). Health effects of occupational exposure to respirable crystalline silica.

Ohene SA, Bonsu F, Adusi-Poku Y, Dzata F, Bakker M. Case finding of tuberculosis among mining communities in Ghana. PLoS One. 2021:16(3):e0248718. https://doi.org/10.1371/journal.pone.0248718

Rambiki E, Dimba A, Ng'ambi W, Banda K, Girma B, Shight B, Kathyola D. The prevalence of pulmonary tuberculosis among miners from the Karonga, Rumphi, Kasungu and Lilongwe Districts of Malawi in 2019. Malawi Med J. 2020:32(4):184–191. https://doi.org/10.4314/mmj.v32i4.2

Rees D, Murray J, Nelson G, Sonnenberg P. Oscillating migration and the epidemics of silicosis, tuberculosis, and HIV infection in South African gold miners, Amer. J. Industr. Med. 2010:53(4):398–404. https://doi.org/10.1002/ajim.20716

Verma DK, Rajhans GS, Malik OP, Des Tombe K. Respirable dust and respirable silica exposure in Ontario gold mines. J Occup Environ Hyg. 2014:11(2):111–116. https://doi.org/10.1080/15459624.2013.843784

World Health Organization. (2023). Tuberculosis [accessed 2024 May 07]. https://www.who.int/news-room/fact-sheets/detail/tuberculosis