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Respirable Dust and Respirable Crystalline Silica Concentration in Workers of Copper Mine, Mongolia

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Abstract

Introduction: Prosperity in the mining industry in Mongolia has led to an increase in the number of mining workers, resulting in an increase in occupational exposures and the prevalence of occupational diseases and disabilities. The aim of this study was to assess the personal exposure of workers to respirable dust (RD) and respirable crystalline silica (RCS). **Method:** A cross-sectional study was conducted at the Erdenet Copper Ore Mining and included 581 personal samples of RD and 324 samples of RCS, collected in 2018-2020. **Results:** The study results revealed that the geometric mean (GM) of RD was 0.35 mg/m^3 (95% CI 0.32 - 0.39). The RD concentration in 5.9% (n = 34) of all the samples exceeded the permissible exposure level (PEL) (3 mg/mg^3). The GM of RCS was 0.012 mg/m^3 (95% CI 0.010 - 0.016). In total, 12.0% (n = 39) of all RCS sample concentrations exceeded the PEL (0.1 mg/m^3). **Conclusion:** Steel smelters, blasters, welders, and maintenance laborers were exposed to RD, while crushers, operators, drilling machinists, and maintenance laborers were exposed to RCS. Therefore, regular monitoring of the work environment, risk-based health examinations for dust-exposed workers, efficient support for dust mitigation, reduction measures at the source, and engineering controls are needed.

Keywords

Copper Mine, Dust Exposure, Respirable, Quartz Silica, Cyclone

1. Introduction

A known issue in the occupational health of the mining industry is exposure to respirable dust (RD). Exploration, mining, blasting, grinding, and surface sanding of mineral resources result in dust. Working with materials such as metals, sand, ceramics, bricks, cement, and stone can produce respirable silica [1] [2]. Silicon dioxide or silica is categorized as a lung carcinogen according to the international classification [3]. There are three different types of crystalline silica: quartz, tridymite, and cristobalite [3]. The most common, toxic and thermodynamically stable in ambient conditions form of crystalline silica is quartz [3]. Occupational risk factors produced during metal mining and metal enrichment processes negatively impact workers' health and can potentially lead to occupational diseases. In particular, occupational exposure to respirable dust (RD) and silica is known to cause lung silicosis, chronic bronchitis, chronic obstructive pulmonary disease (COPD), kidney disease, autoimmune disease, and lung cancer [4] [5] [6] [7] [8]. It is estimated that 1.7 million workers in the United States of America [9], 2 million in Europe [10], and 23 million in China [11] are exposed to occupational respirable crystalline silica (RCS). In 1950-1959, the respirable crystalline dust (RCD) exposure level of Chinese open pit mining workers was 0.75 mg/m^3, whereas, in 1981-1987, it had decreased by 3.7 times to 0.2 mg/m^3. Despite this decrement, workers are still exposed to respirable crystalline silica (RCS) exceeding the permissible exposure level (PEL) of (0.1 mg/m^3) [12].

In 1986-2006, the incidence rates of occupational diseases in coal/mineral mines in Mongolia per 100,000 workers were 155.8 for chronic bronchitis, 83.8 for pneumoconiosis, 6.1 for asthma, and 5.6 for tuberculosis cases. Shagdarsuren *et al.* concluded that the incidence rates of occupational diseases among workers in this sector had increased and were higher than those in other industrial sectors [13]. In Mongolia, although copper ore mining was established in 1978, the capability to determine the RCS level was limited, and equipment and human resources were not available until 2017.

In recent years, as the mining industry in Mongolia has prospered, the number of people working in the mining industry has increased, along with the probability of exposure and occupational disease prevalence. During 2009-2017, more than 80% of occupational disease cases registered at the Occupational Safety and Health Center of Mongolia were found in workers from heavy industries, geology, and mining, whereas over 10% were associated with construction, road construction, and transportation services. According to the Occupational Disease Statistics in 2020, approximately 1573 (53.1%) of the total cases were caused by dust exposure [14]. Furthermore, the vast majority of workers (72.5%), whose disability rate was determined to be due to occupational disease, were reported to be in the mining sector [15].

The Erdenet copper surface mining industry is one of the largest copper ore and molybdenum enrichment and extraction facilities in Asia. Erdenet Mining has registered cases of occupational diseases and has monitored workplace conditions since its founding in 1978. However, there is limited research on the current situation of occupational diseases and occupational exposure. According to Javzmaa *et al.* (2009), the average incidence rate of occupational diseases was 4.6 per 1000 among Erdenet workers in 1980-2008 and in that time the Erdenet Copper Mining evaluated area total dust, and it was found that the total dust concentrations exceeded the national standard (10 mg/m^3) at surface mining, casting, and automobile service centers [16]. However, there is no data on RS and RCS exposure, which is needed to assess risk, and potential controls and efficiency of those controls.

With the advancement of the occupational health sector in Mongolia, new accredited laboratories were established in accordance with international ISO standards, and are implementing NOISH method of respirable dust for measuring occupational hazards and risk factors. We used that new and validated standard methods. The aim of this study was to measure the concentrations of RD and RCS in Erdenet mining workers and evaluate the occupational exposure to these pollutants.

2. Methods

2.1. Study Design

The industrial process of the Erdenet Mining is divided into technological and auxiliary departments. Technological departments include the open-pit (OP), auto transport workshop (ATW), concentrator (CO), maintenance and mechanics workshop (MMW), maintenance and installation department (MID), electricity department (ED), quality monitoring department (QMD), communication, technology, and automation department (CTAD), and research institute (RI). Auxiliary departments include building assembly departments (BAC), thermal power plants (TTP), and steel globe workshops (SGW). A cross-sectional study was conducted from 2018-2020 and included workers from these 12 departments. Workers were selected for our study based on the total dust analysis conducted in previous years at the departments, with high levels of dust exposure that exceeded the permissible exposure level (PEL). RCS and RD samples were collected from 7.1% and 13%, respectively, of the 4500 workers in Erdenet Mining's technology and auxiliary departments. The Research Ethics Review Committee of the Mongolian National University of Medical Sciences approved this study (#2019/3-13).

2.2. Sampling and Analysis

Respirable personal particulate matter samples were collected for a full work shift (8 hours) in the workers' breathing zone according to the National Institute of Occupational Safety and Health (NOISH) method 0600 using 37-mm polyvinyl chloride (PVC) membrane filters (5.0 μm Electron Microscopy Sciences, Hatfield, PA, USA), 3 piece filter cassettes with aluminum cyclone (SKC Inc., Eighty-Four, PA, USA), and personal air sampling pump AirCheck 5000 (SKC

224-44XR, SKC Inc., Eighty-Four, PA, USA) at a flow rate of 2.5 L/min. Before and after sampling, the airflow rate was calibrated using Check-mate (SKC Inc. Eighty-Four, PA, USA). These respirable sample filters were also used for RCS determination. RD concentrations were analyzed gravimetrically for mass concentration in a temperature-and humidity-controlled (22˚C, 35% RH) weighing room using MYA0.8/3.3Y microbalance (Radwag Wagi Elektroniczne, Poland).

The NIOSH 0600 method requires the collection of less than 2 mg of particles on the filter because the collected particles can block the filter, resulting in a lower airflow rate than that of the calibrated air sample. Eight samples overloaded with particles were excluded from further data analysis. The filters were left to equilibrate in the balance room at least 8 h prior to pre- and post-weighing, and each filter was weighed three times. The average of three weights was used as the filter mass. The quartz silica samples were analyzed according to the NIOSH method 7602 using Fourier-transform infrared spectroscopy (FTIR, Bruker Alpha, Germany). Quartz silica was measured at 694 $s \cdot m^{-1}$ wavelengths, and the limit of detection (LOD) of the equipment was <0.001 mg/m^3. All analyses were performed in ISO/IEC 17025:2007/2018 standard accredited laboratories (Occupational Health and Safety Laboratory of School of Public Health, and H Analytics Laboratory of Health and Safety Solutions LLC). One blank field sample per sampling day (approximately 10.8% of the samples) was collected for quality control.

2.3. Statistical Method

Summary descriptive statistics such as geometric means (GM), geometric standard deviations (SD), arithmetic means (AM), and 95% confidence interval of arithmetic and geometric mean (95% CI) and box-and-whisker plots were generated using STATA (Stata Statistics, version 15, StataCorp LLC, 2017) and SPSS software (IBM SPSS Statistics, version 22.0). Data were tested for normality using the Wilkes-Shapiro test ($p = 0.0000$). Respirable dust and RCD concentrations were compared to PEL in the Mongolian National standard MNS4990:2015 [17]. The difference between measurements in each of the departments and occupations were investigated with a one-way ANOVA test. A p-value lower than 0.05 was considered as statistically significant.

3. Results

The baseline study included 581 personal RD samples and 324 personal quartz silica samples which were collected from 12 departments. The number of blanks used was 63. The average working years of participants was 9.7 ± 8.2 years; minimum and maximum working years were 1 year and 40 years, respectively. Among the total participants, 42.3% had worked for 1 - 5 years, 20.4% for 6 - 10 years, 12.4% for 16 - 20 years, and 12.4% for more than 21 years.

The GM (±SD) and AM of RD in 2018-2020 was 0.35 (±0.56) mg/m^3 and 0.91 mg/m^3, respectively. The main airborne concentration of RD in the workplace was slightly higher in 2020 than in 2018. Overall, the personal samples of 34 workers in the selected departments were estimated to be at risk of RD exposure (Figure 1).

Table 1 shows the number of observations, arithmetic means (AM), geometric means (GM), geometric standard deviations (SD), minimum (Min), maximum (Max), and percentage (number) above the PEL of RD and RCS concentrations by department in the Erdenet mine.

According to the samples obtained from the different departments, RD was high in samples (n = 19) from the concentrator (CO). The highest concentration of RD was found in the Concentrator (18.43 mg/m^3). Thirty-four samples exceeded the PEL, including in the Concentrator, open-pit, maintenance, and mechanical workshops. There were no statistically significant differences in RD among the different departments (p = 0.377). The GM of RD was higher in steel smelters, welders, maintenance laborers, crushers, and ore samplers (p = 0.004, Table 2). The RD exposure was above PEL of Mongolian national standard (MNS 3 mg/m^3) in steel smelters, maintenance workers, welders, and blasters.

In 60 samples (18.7%), the concentrations of RCS were lower than the limit of detection (0.001 mg/m^3), of the equipment. The GM (±SD) and AM of RCS in 2018-2020 were 0.012 (±0.74) mg/m^3 and, 0.049 mg/m^3 respectively. The quartz silica measurements of 2019 were relatively higher compared with the other years. In 14.8% or 39 samples (Figure 1), the RCS concentrations exceeded the MNS PEL (0.1 mg/m^3).

From the results of the RCS samples studied from 12 different departments (Table 1), the sample from the sample preparation room of research institute had the highest RCS, with an GM of 0.037 mg/m^3. Thirty-one samples from this area exceeded the MNS PEL. Furthermore, the RCS measurements of six workers from the open-pit mining area exceeded the MNS PEL.

Quartz silica concentrations differed according to the workers' job tasks (p = 0.0005). The RCS measurement of maintenance laborers, operators, crusher, and

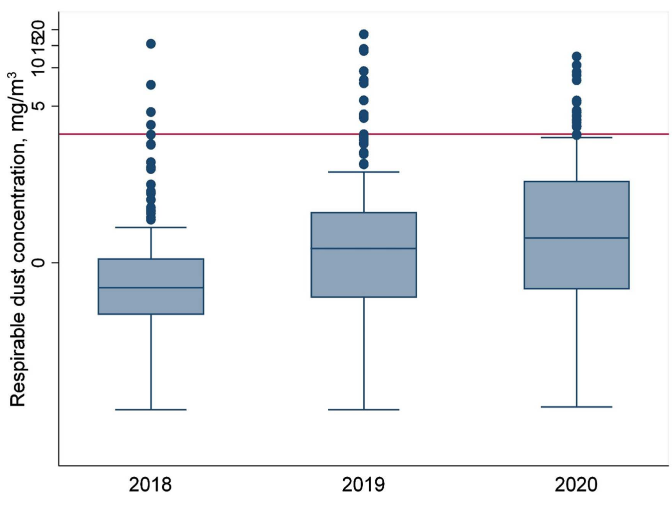

Figure 1. Respirable dust concentration by year.

Table 1. Descriptive statistics of respirable dust and quartz silica by departments.

Departments	N	AM, mg/m³	GM, mg/m³	GSD, mg/m³	Min, mg/m³	Max, mg/m³	% (n) > PEL
Respirable dust (*p = 0.377*), *PEL = 3* mg/m³							
OP	88	0.82	0.29	0.58	0.03	8.03	5.7 (5)
ATW	76	0.72	0.24	0.54	0.02	15.50	2.6 (2)
CO	309	0.90	0.37	0.54	0.02	18.43	6.1 (19)
MMW	30	1.90	0.81	0.61	0.06	12.3	16.7 (5)
MID	12	0.82	0.53	0.45	0.10	2.23	0
ED	6	0.41	0.32	0.31	0.15	1.04	0
QMD	9	1.01	0.39	0.62	0.06	4.61	11.1 (1)
CTAD	14	0.85	0.42	0.58	0.05	2.95	0
RI	6	1.70	1.46	0.29	0.41	2.63	0
BAC	6	0.67	0.34	0.69	0.03	1.40	0
TTP	18	1.16	0.39	0.62	0.06	8.76	11.1 (2)
SGW	7	0.33	0.13	0.61	0.03	1.56	0
Total	**581**	**0.91**	**0.35**	**0.74**	**0.02**	**18.43**	**5.9 (34)**
Respirable crystalline silica (*p = 0.0001*), *PEL = 0.1* mg/m³							
OP	44	0.042	0.068	0.0103	0.001	0.366	13.6 (6)
ATW	51	0.006	0.009	0.003	0.001	0.051	-
CO	101	0.085	0.121	0.024	0.001	0.588	30.7 (31)
MMW	19	0.032	0.032	0.021	0.003	0.048	-
MID	5	0.026	0.027	0.014	0.004	0.064	-
ED	3	0.011	0.008	0.01	0.006	0.021	-
QMD	8	0.023	0.018	0.018	0.006	0.052	-
CTAD	6	0.010	0.016	0.005	0.001	0.042	-
RI	7	0.045	0.028	0.037	0.013	0.101	14.3 (1)
BAC	4	0.035	0.032	0.022	0.004	0.080	-
TTP	12	0.073	0.126	0.024	0.001	0.437	8.3 (1)
SGW	4	0.016	0.016	0.009	0.003	0.038	-
Total	**264**	**0.049**	**0.090**	**0.012**	**0.001**	**0.588**	**14.8 (39)**

OP = open-pit, ATW = auto transport workshop, CO = concentrator, MMW = maintenance and mechanics workshop, MID = maintenance and installation department, ED = electricity department, QMD = quality monitoring department, CTAD = communication, technology, and automation department, RI = research institute, BAC = building assembly departments, TTP = thermal power plants, and SGW = steel globe workshops. AM = arithmetic mean, SD = standard deviation, GM = geometric mean, PEL = permissible exposure limit.

Table 2. Descriptive statistics of respirable dust and of quartz silica by profession.

Occupation	N	AM (95% CI), mg/m^3	GM (95% CI), mg/m^3	GSD, mg/m^3	% (n) > PEL
***Respirable dust* (*p* = *0.004*)**					
Maintenance laborer	197	1.23 (0.87 - 0.1.60)	0.44 (0.36 - 0.53)	0.58	8.1 (16)
Operators	98	0.61 (0.40 - 0.83)	0.27 (0.21 - 0.34)	0.54	2.0 (2)
Heavy vehicle drivers	58	0.37 (0.25 - 0.48)	0.22 (0.17 - 0.29)	0.41	-
Crusher	40	0.88 (0.53 - 1.23)	0.43 (0.29 - 0.64)	0.53	5.0 (2)
Welder	39	1.15 (0.48 - 1.82)	0.50 (0.33 - 0.77)	0.57	10.3 (4)
Miller	27	0.60 (0.31 - 0.88)	0.36 (0.24 - 0.54)	0.45	3.7 (1)
Drill machinist	22	0.89 (0.34 - 1.43)	0.32 (0.16 - 0.63)	0.66	4.5 (1)
Crane machinist	20	0.32 (0.23 - 0.42)	0.25 (0.17 - 0.37)	0.37	-
Blaster	17	1.62 (0.05 - 3.20)	0.31 (0.12 - 0.78)	0.78	17.6 (3)
Steel smelter	10	2.75 (0.81 - 4.69)	1.58 (0.62 - 4.02)	0.57	40.0 (4)
Ore sampler	12	0.94 (0.08 - 1.80)	0.41 (0.17 - 0.98)	0.59	8.3 (1)
Filterer	10	0.24 (0.10 - 0.39)	0.19 (0.11 - 0.32)	0.33	-
Surveyor	9	0.28 (−0.10 - 0.66)	0.13 (0.06 - 0.31)	0.47	-
Rigger and spotter	11	0.89 (0.27 - 1.51)	0.55 (0.27 - 1.09)	0.45	-
Other	11	0.33 (0.17 - 0.49)	0.24 (0.13 - 0.44)	0.38	-
***Respirable crystalline silica* (*p* = *0.0001*)**					
Maintenance laborer	90	0.051 (0.029 - 0.072)	0.011 (0.008 - 0.017)	0.74	12.2 (11)
Operators	32	0.098 (0.044 - 0.152)	0.027 (0.013 - 0.052)	0.81	34.4 (11)

Continued

Heavy vehicle drivers	33	0.011 (0.004 - 0.018)	0.004 (0.003 - 0.007)	0.55	-
Crusher	24	0.105 (0.071 - 0.139)	0.073 (0.048 - 0.111)	0.43	41.7 (10)
Welder	19	0.018 (0.002 - 0.035)	0.009 (0.004 - 0.015)	0.53	5.3 (1)
Miller	11	0.021 (−0.014 - 0.057)	0.006 (0.002 - 0.015)	0.62	9.1 (1)
Drill machinist	14	0.064 (0.035 - 0.093)	0.032 (0.012 - 0.082)	0.71	21.4 (3)
Blaster	8	0.018 (−0.014 - 0.050)	0.005 (0.001 - 0.018)	0.67	12.5 (1)
Steel smelter	8	0.046 (0.017 - 0.076)	0.033 (0.014 - 0.076)	0.44	-
Ore sampler	7	0.017 (0.005 - 0.029)	0.014 (0.007 - 0.027)	0.33	-
Filterer	10	0.024 (−0.007 - 0.055)	0.006 (0.002 - 0.022)	0.73	10.0 (1)
Other	8	0.012 (−0.001 - 0.027)	0.013 (0.002 - 0.019)	0.61	-

AM = arithmetic mean, SD = standard deviation, GM = geometric mean, PEL = permissible exposure limit, PEL = 3 mg/m^3 for respirable dust, PEL = 0.1 mg/m^3 for respirable crystalline silica.

drill machinists exceeded the MNS PEL compared with the other professions (**Figure 2**). The highest concentration of RCS was determined in workers from the concentrator, at 0.588 mg/m^3.

4. Discussion

Erdenet, the second largest mine in Mongolia, is a surface copper ore mine founded 40 years ago; however, until 2018, respirable personal particulate matter (PM) measurements were not conducted. Instead, evaluation and monitoring of the occupational environment were conducted through area total dust samples collection and investigation.

Previous occupational exposure studies in Mongolia measured area total dust exposure in coal miners [18], asbestos exposure in thermal power plant workers [19], and personal PM exposure of traffic policemen in Ulaanbaatar, Mongolia [20]. The samples collected in these previous studies were evaluated in occupational health laboratories in South Korea and the USA. The establishment and accreditation of the Occupational Health Laboratory at the School of Public Health in 2017 provided an opportunity to study personal exposure to RD and RCS in Mongolia.

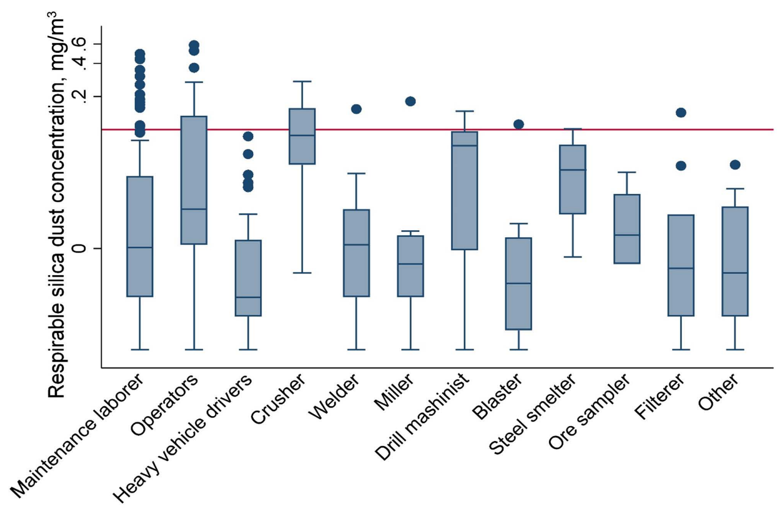

Figure 2. Personal exposure to Respirable crystalline silica by occupation.

Exposure to RD and RCS depend on the mineral type of the mine. Previous studies have evaluated the exposure of mining workers to RD and RCS in coal in the US [21], copper in Zambia [22], iron in Sweden [23], and talc mining in the US [24], but no study has been conducted in Mongolia. According to the literature, underground mining workers are exposed to higher levels of RD and RCS than surface mining workers [5] [21] [25].

In 1972, the USA reduced the PEL for RD from 3 mg/m^3 to 2 mg/m^3 [21]. However, in Mongolia, the PEL remained the same at 3 mg/m^3 (MNS4990:2015). Based on the present study, 5.9% (n = 34) of the overall RD samples exceeded the PEL, although 16.7% of maintenance and mechanics workshop samples exceeded the PEL, indicating that some of the departments are at higher risk and may require more effort to control exposures. Based on their profession, 40% of steel smelters, 17.6% of blasters, 10% of welders, 8% of maintenance laborers and ore samplers, and 5% crushers are being exposed above the PEL. Previous literature has indicated similar findings, where drillers, crushers, maintenance workers, and mechanics were found to be exposed to high levels of RD [5] [21].

Cauda *et al.* reported a lack of monitoring and evaluation of RCS compared with RD [26]. The same situation was observed in the Mongolian mining industry until recently. Quartz silica measurements and evaluations were unavailable owing to the lack of an occupational health laboratory. The PEL for quartz silica in the workplace is 0.1 mg/m^3 in Mongolia, whereas other countries have reduced the exposure limits. For instance, in 2007, the American Conference of Governmental Industrial Hygienists (ACGIH) [27] reduced the 8-hour exposure threshold limit value (TLV-TWA) from 0.05 mg/m^3 to 0.025 mg/m^3, and in Europe the Scientific Committee on Occupational Exposure limit (SCOEL) [28] advises the PEL to be 0.05 mg/m^3. The present study determined the GM of quartz silica among Erdenet mining industry workers to be 0.012 mg/m^3. This result is 1.7 times higher than the findings (GM 0.007 mg/m^3) of Scarselli *et al.*

[29], but 1.6 times lower than the findings (GM 0.02 mg/m^3) of Peters *et al.* [7]. The differing results of these studies could be due to the different dust reduction measures implemented at mining sites, climate, and geographical location.

Based on the present study, overall, 14.8% or 39 RCS measurements exceeded the PEL of Mongolia by 2 - 6 times. If these samples are evaluated in accordance with other exposure limits, 24.2% or 66 samples exceeded the PEL-TWA (0.05 mg/m^3) of Occupational Safety and Health Administration (OSHA) and 34.1% or 93 samples exceeded the TLV of ACGIH. By profession, 41% of crushers, 34% of operators, 21% of drill machinists, and 12% of maintenance workers and blasters, and 30% of concentrator workers are exposed to silica dust above the PEL. Similarly, in a study conducted at Cananea mining, workers at copper ore processing plants were exposed to crystalline silica at levels 10 times higher than the PEL [30]. If the samples obtained from workers in this study are compared to PELs of OSHA, workers of other departments at Erdenet mining, such as open-pit, maintenance and mechanical workshops, and maintenance and installation departments, are exposed to 1.2 - 11.7 times higher than OSHA PEL of quartz silica. According to other studies, drillers of surface and underground mining, blasters, exploration, ore samplers, heavy vehicle drivers, maintenance workers, cleanup, and mechanical truck drivers are exposed to high levels of silica dust [5] [7] [30]. Additionally, crystalline silica size lower than 0.3 μm is found to be associated with increased production of reactive oxygen species [21]. Therefore, it is vital to focus on quartz silica levels in future studies.

The present study showed that the exposure levels of RD and RCS differed according to profession, workplace, and occupational features. This study highlights the importance of constant monitoring and evaluation of workers' exposure to RD and RCS, along with the implementation of a constant risk assessment of occupational hazards in order to be able to implement targeted and efficient interventions aimed at decreasing exposure to RD and RCS.

5. Conclusion

The present study evaluated personal exposure to RD and quartz silica in Erdenet mining workers. The study population was workers at Erdenet Mining, and samples were collected during 2018-2020. The study results showed a further need for occupational exposure assessment and worker health monitoring. Furthermore, the study findings provide an opportunity to identify similar exposure groups. Some workers were potentially exposed to elevated RD (5.9%) and RCS (14.8%) levels. Compared to the OSHA-PEL, the number of workers exposed to quartz silica increased by 1.6 times. Quartz silica is a carcinogen; therefore, the Mongolian national PEL value must be reduced in accordance with international recommendations. Respiratory diseases caused by RD, especially those at risk of exposure to quartz silica, need to be addressed and prevented. Additionally, the research team highlighted the need for a unified database of occupational health measurements.

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Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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