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Original article

Artisanal Gold Mining in Mongolia: Silica Exposure and Silicosis Risk Factors-Field Survey

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Background: Silicosis remains a critical occupational health challenge, particularly among artisanal and small-scale gold miners (ASGM). This study investigates the prevalence of silicosis and its associated risk factors, while assessing the levels of respirable dust and crystalline silica exposure in Mongolian artisanal miners.

Methods: A cross-sectional survey was conducted with 124 employees of the Tsagaan Tsakhir artisanal gold miners in Bayankhongor Province, Mongolia. Participants completed questionnaires and underwent medical exams, including spirometry and X-rays. Dust samples ($n = 10$) were collected during a working day, and the workplace was divided into underground exploration and outdoor grinding areas. Multivariate analysis evaluated risk factors for silicosis.

Results: Underground quarrying (dry) showed the highest exposures (dust geometric mean (GM): 8.107 mg/m^3; silica GM: 2.156 mg/m^3), followed by grinding (dust GM: 1.374 mg/m^3; silica GM: 0.555 mg/m^3). Wet quarrying and packaging tasks had significantly lower levels. A total of 124 male participants (mean age 35.9, mean work years 5.7) were included. Twenty four participants (19.4%) had silicosis, with 58% having profusion 2 or higher. Multivariate analysis showed increased odds of silicosis with longer work years (OR = 2.6) and specific work positions (e.g., underground drilling: OR = 6.23).

Conclusion: Artisanal gold miners in Mongolia face significant health risks due to high silica exposure and inadequate protective measures. Urgent interventions, including improved dust control and routine medical surveillance, are needed to mitigate silicosis risks in this vulnerable population.

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1. Introduction

Artisanal and small-scale gold mining (ASGM) is an informal mining operations characterized by manual labor and basic equipment, primarily undertaken by individuals or small groups without formal mining rights. ASGM supports the livelihoods of over 100 million individuals worldwide and accounts for approximately 20% of global gold production [1]. However, this sector is fraught with significant health risks, particularly in low-income countries with inadequate regulatory oversight. Studies from regions like Tanzania and Zimbabwe have highlighted how exposure to crystalline silica dramatically increases the incidence of silicosis and other respiratory illnesses among miners [2,3].

In Mongolia, ASGM has become a vital source of income, particularly for rural communities where alternative employment opportunities are scarce. Known locally as “ninja mining”, this informal sector has grown substantially since the 1990s. In 2017, ASGM contributed 63.3% (12.66 tons) of the country’s total gold production [4]. Despite its economic contributions, workers in this sector often face hazardous conditions without adequate protective equipment or safety regulations [5].

Prolonged exposure to respirable crystalline silica is a primary cause of silicosis, a chronic and often fatal lung disease [6,7]. The World Health Organization recommends lifelong health surveillance for workers exposed to silica dust, with baseline chest X-rays at the start of employment and follow-up screenings every 2–3 years [8]. However, in Mongolia’s ASGM sector, such health monitoring practices are rarely implemented.

Mongolia’s ASGM sector lacks a formal occupational health and safety (OHS) framework. Approximately 66% of workers in this sector do not have access to basic healthcare services, exposing them to preventable diseases and injuries [9,10]. While international guidelines from organizations such as the International Labour Organization (ILO) provide clear safety standards [11], their enforcement remains limited in this context.

There is limited research assessing the health impacts of dust exposure among Mongolia’s ASGM workers. This study aims to address the existing gaps by evaluating the respiratory health of artisanal gold miners of the Tsagaan Tsakhir in Bayankhongor Province and quantifying their exposure to occupational dust, including respirable crystalline silica.

2. Methods

This small-scale mining has the capacity to process 10 tons of ore a day. Partially operational (304 days a year excluding maintenance and standstill periods). If fully operational, it is possible to produce 85–90 kg of gold a year. It serves formal artisanal miners working on license areas of Special Mines LLC with tri-partite agreement, informal miners in the same field, and both formal and informal artisanal miners working in the Western region [4].

2.1. Clinical assessment

Currently, there are about 250 artisanal miners in Bayankhongor province. The processing plant in Bayankhongor province has a 1 jaw crusher, 4 roller mills, and 2 hammer mills. Eligible participants in the present study were comprised of all artisanal gold miners in Bayankhongor province, Mongolia, by the Khongor Khuder Limited Liability Company during 01 Jul 2020-03 Jul 2020. Overall, 147 workers at the artisanal gold mining industry were enrolled. Those who were women ($n = 19$), with incomplete questionnaire regarding dust-related working history ($n = 1$), and without chest X-ray results or low quality of chest X-ray ($n = 3$) were excluded. A total of 124 artisanal gold miners were included as final eligible population for the present study. The present study was performed under the guidance of the Declaration of Helsinki. Written informed consent from participants was taken before this preliminary study. The study protocol was approved by the Biomedicine Commission of Mongolian National University of Medical Science (№2020.3-05).

The spirometry was calibrated by experienced technicians before the examination with the 3-liter high-precision volume calibration syringe (Medikro ® M9474, Kuopio, Finland) according to 2005 American Thoracic Society/European Respiratory Society guideline [12] prediction model for China, with Asian ethnicity. The pulmonary function test was performed using a portable spirometry (Medikro ® pro, Kuopio, Finland) by two experienced technicians. The spirometry results (FVC (forced vital capacity), FEV_1 (forced expiratory volume in 1 second), FEV1/FVC) were measured according to Occupational Safety and Health Administration U.S. Department of Labor criteria. The spirometry prediction model was based on the Coal Steel Communication, with the ethnic group being the Asia population [13].

An experienced technician for X-ray had performed a chest X-ray to evaluate the respiratory diseases such as pneumoconiosis, tuberculosis, effusion, etc. Those who had experienced pneumoconiosis evaluation for 10 or more years had participated to check the pneumoconiosis status among artisanal gold miners according to ILO 2011 guideline for pneumoconiosis [14]. Those with unacceptable chest x-ray quality had been discarded for evaluating pneumoconiosis. Two radiologists checked pneumoconiosis status. The unmatched results were estimated by a third reader [14].

2.2. Mining process and environment measurement

The gold mining process consisted of rock quarrying underground, roping workers, and raw materials, unloading and packaging, grinding, washing and waste dumping process. Work environments were assessed: rock quarrying with drilling, unloading and packaging and grinding process. Their jobs were classified as underground drilling and assistant, packaging, overground grinding and assistant, and head, roping and others. The work years were assessed by questions for “how long did you work in underground mining work in your whole work history?“, the total work years were assessed by asking “how long did you work in ASGM mining work in your whole work history?“. Proper mask usage was defined in the questionnaire as wearing a respiratory protective device such as an N95-equivalent throughout the work shift whenever dust exposure occurred.“

Personal samples from the work environment were obtained with battery operated pumps (AirCheck 5000, SKC Inc., PA, USA) with 37-mm polyvinyl chloride membrane filters (5.0 μm), filter cassettes with aluminum cyclones (flow rate: 2.5 L/min; NOISH method 0600) in the breathing zone of workers clipped to the lapel area with the cyclones hanging vertically downward. Sample durations ranged from 2 to 6 hr. For areal air sampling for evaluating work environment, the collecting inlet was positioned at locations approximately 1–2 meters above the ground near crushing, hammering, and loading operations. Respirable dust was defined operationally by our sampling device (cyclone with 50% cut-point ~4 μm). Fourier-transform infrared spectroscopy (FTIR, Bruker Alpha, Germany) was applied to analyze the contents of crystalline silica under the guidance of NIOSH (NIOSH method 7602). The details of analysis of crystalline silica are provided elsewhere [15]. The underground quarrying process was conducted using both dry and wet methods in artisanal gold mining on-site. Both wet and dry environmental conditions were assessed together. The air temperature was 25.6°C and relative humidity 34.8% were shown when it was performed on 20 Jul 2020.

2.3. Statistical analysis

The whole statistical analysis was done with SAS ver 9.4 (SAS institute, Cary, NC, USA). The general characteristics were shown as means and standard deviation (SD). The concentration of air samples was shown as geometric means (GM) and geometric standard deviation (GSD). The test of normality was assessed for work duration and working time a day with the Kolmogorov-Smirnov test. The difference of continuous values and categorical variables by pneumoconiosis or not were estimated Student t test and chi-square test, respectively. In addition, multiple logistic regression analysis was performed to estimate the association of prevalent pneumoconiosis and working characteristics among artisanal gold miners in Bayankhonor province.

3. Results

3.1. Characteristics of study population

A total 124 male participants; mean age 35.9 ± 10.2, total working years were 5.7 ± 3.5 in this survey.

Miners were young but their pulmonary function was generally decreased FEV1 (%) was 79.3 ± 13.6. The smoking prevalence was high at 72.4% among the miners. The findings showed high prevalence of silicosis was 19.4% (24) and silicosis (second and third stage) with 58% (14) of cases (Table 1).

3.2. Respirable dust and silica component levels of artisanal miners

Figure 1 illustrates the artisanal gold mining process in Bayankhongor Province, outlining the key steps involved in each mining activity. Table 2 demonstrates the geometric mean (GM) and GSD of dust and silica levels across various tasks, identifying underground quarrying (dry) as the most hazardous activity, with the highest respirable dust (GM: 8.107 mg/m^3; GSD: 1.11) and crystalline silica levels (GM: 2.156 mg/m^3; GSD: 1.17). Grinding also showed significantly elevated concentrations of respirable dust (GM: 1.374 mg/m^3; GSD: 4.59) and crystalline silica (GM: 0.555 mg/m^3; GSD: 4.47). While underground quarrying (wet) exhibited lower dust levels (GM: 0.110 mg/m^3), silica exposure (GM: 0.040 mg/m^3) remained a risk. Packaging tasks had comparatively lower levels of dust (GM: 0.189 mg/m^3; GSD: 5.30) and silica (GM: 0.091 mg/m^3; GSD: 2.80) but were still concerning (Table 2).

Silicosis was notably prevalent among individuals working underground and those in the head position of small-scale mining, with an average daily working duration of 9.7 ± 3.5 hours. Furthermore, only 15.5% of the miners reported using protective masks (Table 3).

A multivariate analysis showed that the odds ratio for silicosis in mining work years (per 5 years) 2.6 (95% confidence intervals (CIs): 1.35–5.26), work positions: underground drilling and assistant (OR: 6.23; 95% CIs:1.00–121.39), packaging (OR: 5.25; 95% CIs:0.43–125.88), head, roping, and other (OR: 4.83; 95% CIs: 0.77–94.78) and proper mask use (OR: 0.98; 95% CIs:0.23–3.44) (Table 4).

Table 1
General characteristics of artisanal gold miners

Variables	N	Means (%)	SD
Age (year)	124	35.9	10.2
Height (m)	124	1.70	0.10
Weight (kg)	124	74.9	15.8
BMI	124	25.6	4.80
Smoking status			
Current smoker	89	72.4	
Ex-smoker	9	7.3	
Nonsmoker	25	20.3	
Mean smoking years	98	15.5	9.7
Cigarette per day	98	14.1	6.7
Pack-year	98	24.4	21.3
Previous medical history			
Tuberculosis	5	4.1	
COPD	3	2.5	
Asthma	3	2.5	
Pulmonary function profiles			
Predicted FVC (L)	114	4.09	0.62
FVC (%)	114	97.2	18.1
Predicted FEV1(L)	114	4.07	0.65
FEV1 (%)	114	79.3	13.6
FEV1/FVC	114	0.81	0.08
Predicted FEF50 (L)	114	4.84	0.59
Predicted FEF75 (L)	114	2.06	0.36
Predicted FEF25_75 (L)	114	3.93	0.54
Silicosis			
No	100	80.7	
Yes	24	19.4	
Total	124	100.0	

SD, Standard deviation; BMI, body mass index; COPD, chronic obstructive pulmonary disease; FVC, forced vital capacity; FEV1, forced expiratory volume 1.

4. Discussion

Our study of artisanal and small-scale gold miners in Tsagaan Tsakhir, Bayankhongor province of Mongolia, revealed significant occupational health risks. We found a high prevalence of silicosis 19.4%, with 58% of cases showing advanced stages, despite a relatively short average work duration of 5.7 years. Respirable dust and crystalline silica exposure levels frequently exceeded permissible limits, particularly in underground mining and grinding operations. A longer work duration and specific job positions, especially underground drilling, were associated with increased silicosis risk. These findings highlight the urgent need for improved dust control measures, occupational health services, and targeted interventions in Mongolia's artisanal mining sector.

Globally, silicosis continues to be a significant occupational health burden. Shi et al reported a 66% increase in global silicosis cases between 1990 and 2017, with crystalline silica exposure accounting for approximately 40% of cases [16]. In Mongolia, silicosis represented 54% of all occupational disease disabilities in 2017, underscoring its significant impact on worker health [16]. The observed 19.4% prevalence of silicosis among our study population is concerning, especially considering the relatively short average work duration of 5.7 years. Such findings highlight the urgent need to situate Mongolia's occupational health challenges within the broader global context. This prevalence aligns with rates reported in other ASGM studies globally, ranging from 11% to 37% (e.g., Brazil: 10.5% and 37%; China: 29.1%; Tanzania: 30%) [17]. Moreover, the high proportion of cases (58%) with profusion 2 or higher indicates potentially rapid disease progression, likely driven by intense silica exposure. ILO profusion 2 or more grades of silicosis were diagnosed in small scale mining 50% (604), medium 40.4% (500), and large mining 23.6% (414) in Hebei China [18]. Although miners have only a few years (5.7 ± 3.5) of work experience, relatively long working hours (9.7 ± 3.5) per day have led to a high number of silicosis cases. The rapid onset and high prevalence of silicosis among Mongolian ASGM workers, despite short work durations, underscore the critical importance of implementing effective dust control measures, improving occupational health services, and developing targeted interventions for this vulnerable worker population.

Multivariate analysis revealed that specific job positions, particularly underground drilling (OR = 6.23), were also associated with higher risk. These findings emphasize the cumulative nature of silica exposure risk and the importance of job-specific

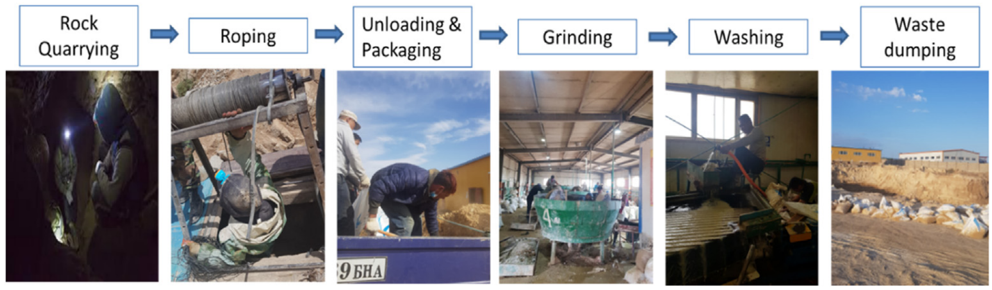

Fig. 1. Artisanal gold mining process in Bayankhongor Province.

interventions. In this study, respirable crystalline silica levels exceeded the Permissible Exposure Limit (PEL) values recommended by Occupational Safety and Health Administration (OSHA) (0.1 mg/m^3) [19] and National Institute for Occupational Safety and Health (NIOSH) (0.05 mg/m^3) [7], particularly among underground workers. Underground quarrying (dry) showed the highest exposure levels, with a geometric mean (GM) of 2.156 mg/m^3 for respirable crystalline silica—far exceeding international safety thresholds. Comparatively, the GM of respirable crystalline silica was 0.012 mg/m^3 (95% CI: 0.010–0.016 mg/m^3) in large scale Mongolian copper mines have been reported [15]. It revealed that the ASGM's environment was worse than large-scale miner's environment. Wet processes observed in underground quarrying demonstrated relatively lower concentrations (GM: 0.040 mg/m^3 for silica), highlighting the necessity of transitioning to wet methods to mitigate exposure risks effectively.

Table 2
Respirable dust and silica component levels of artisanal gold miners by their major work

Variables	Respirable dust (mg/m^3)		Crystalline silica dust (mg/m^3)	
	GM	GSD	GM	GSD
Grinding (n = 4)	1.374	4.59	0.555	4.47
Package (n = 2)	0.189	5.30	0.091	2.80
Underground quarrying (Wet) (n = 1)	0.110		0.040	
Underground quarrying (Dry) (n = 2)	8.107	1.11	2.156	1.17

SD, Standard deviation; GM, geometric mean; GSD, geometric standard deviation.

Due to limitations inherent in surveying informal sector workers under constrained field conditions, our study was unable to fully capture detailed job rotation patterns or comprehensive cumulative exposure data. However, acknowledging the significance of potential job rotations, we attempted to partially mitigate this issue by separately considering the duration specifically associated with dust-exposed tasks versus total employment duration. Future studies should incorporate comprehensive occupational histories or apply formalized methods such as job-exposure matrices to enhance exposure assessment accuracy.

The nature of ASGM work, characterized by long daily working hours (9.7 ± 3.5 hours on average) in poorly ventilated underground environments, may contribute to this intense exposure. Unlike larger mining operations with established dust control measures, small-scale mines often lack proper engineering controls and personal protective equipment. In addition, although a negative dose response relationship between the size of the mine and the prevalence of pneumoconiosis has been observed, small-scale miners' duration of exposure of 8.1 ± 5.3 was shorter than big-scale miners with duration of exposure of 15.5 ± 6.2. Medium-scale miners had an exposure of 11.0 ± 6.4 years, respectively [16]. Multivariate analysis revealed that longer work duration significantly increased the odds of developing silicosis (OR = 2.6 per 5 years). Given the high levels of dust exposure and rapid onset of silicosis observed in ASGM workers, implementing regular medical screening programs is crucial for early detection and management of this irreversible and progressive disease. Between 1996 and 2006, the life expectancy and the expected years of life loss of a patient with silicosis were 18.1 and 9.5 years, respectively, in Mongolia [20]. By establishing robust medical screening programs, we can potentially reduce the incidence of

Table 3
Occupational characteristics of artisan gold miners

Variables	Total			Silicosis						*p* value
				No			Yes			
	N	Mean (%)	SD	*N*	Mean (%)	SD	*N*	Mean (%)	SD	
Occupational classification										
Assistant in overground	25	(20.1)		24	(24.0)		1	(4.2)		0.045
Underground drilling and assistant	40	(32.3)		28	(28.0)		12	(50.0)		
Package	14	(11.3)		12	(12.0)		2	(8.3)		
Head, roping, and other	45	(36.3)		36	(36.0)		9	(37.5)		
Proper mask usage*										
No	104	(84.5)		85	(85.0)		19	(82.6)		0.775
Yes	19	(15.5)		15	(15.0)		4	(17.4)		
Mining work years (year)	124	5.7	3.5	100	5.2	3.7	24	8.2	3.7	0.481
Total work years (year)	124	13.1	8.4	100	12.8	8.5	24	14.2	7.9	0.001
Working hour per day (hour)	124	9.7	3.5	100	9.6	3.2	24	10.2	4.6	0.856
Total	124	(100.0)		100	(100.0)		24	(100.0)		

* data from 124 respondents; 1 missing.
SD, Standard deviation

Table 4
The association between presence of silicosis in chest X-ray and occupational characteristics of artisanal gold miners

Variables	Crude		Multivariate analysis	
	OR	(95% CI)	OR	(95% CI)
Mining work years (per 5 years)	1.22	(1.08−1.38)	2.60	(1.35−5.26)
Occupational classification				
Assistant in overground	1		1	
Underground drilling and assistant	9.43	(1.13−78.41)	6.23	(1.00−121.39)
Package	4	(0.33−48.65)	5.25	(0.43−125.88)
Head, roping, and other	6.00	(0.71−50.46)	4.83	(0.77−94.78)
Proper mask usage				
No	1		1	
Yes	1.19	(0.356−4.00)	0.98	(0.23−3.44)

SD, Standard deviation
Adjusted mining work years (per 5 years), occupational class, proper mask usages in the multiple logistic regression analysis.

advanced silicosis cases and their associated complications. This approach is not only beneficial for individual workers but also contributes to the overall sustainability and social responsibility of the ASGM sector. In addition to medical screening, implementing robust workplace management practices that effectively control dust exposure at the source is critical for primary prevention. Key interventions include employing wet drilling techniques, ensuring sufficient workplace ventilation, and appropriately enclosing equipment used in grinding and other dust-generating tasks. Alongside these engineering controls, consistent and correct use of respiratory protective equipment should be encouraged.

It is noteworthy that the smoking prevalence in our cohort (72.4%) far exceeds the national average for Mongolian males (51%) [21], potentially exacerbating pulmonary health risks. For the national statistics of respiratory disease such as asthma (there is limited report on chronic obstructive pulmonary disease (COPD) prevalence in Mongolia), the prevalence of asthma among Mongolian adult was 2.1%, which was concordant with asthma prevalence among ASGM workers in this study [22]. However, aside from smoking and occupational exposure, detailed medical histories (e.g., COPD and asthma) were not available for our participants due to low accessibility for diagnosis in rural areas, which we now recognize as a study limitation.

This study has several important limitations that should be considered when interpreting the results. The cross-sectional design, while providing valuable insights, restricts our ability to establish causal relationships between exposure factors and health outcomes. By capturing data at a single point in time, we cannot definitively determine the temporal sequence of events or account for changes in exposure levels over time. Additionally, the study's focus on a single mining area in Bayankhongor Province may limit the generalizability of our findings to other ASGM operations across Mongolia, as working conditions and exposure levels may vary significantly between sites. The reliance on self-reported work histories introduces the potential for recall bias, which could affect the accuracy of exposure assessments and risk factor analyses. Participants may have difficulty accurately recalling the duration or intensity of their dust exposure, particularly for events that occurred in the distant past. As this study was conducted as a pilot investigation, we did not perform an a priori sample size calculation, which may have resulted in inflated statistical estimates. Therefore, future research targeting ASGM workers should utilize the effect sizes derived from this study to appropriately calculate and ensure adequate statistical power. To address these limitations and strengthen the evidence base, future research should prioritize longitudinal studies that encompass a broader range of ASGM sites across Mongolia.

In summary, these findings demonstrate that small-scale gold miners in Mongolia are exposed to significant occupational respiratory health risks. This highlights the urgent need for improvements in mining technology and the resolution of occupational safety and health measures for small-scale gold mining at the national level.

CRediT authorship contribution statement

Densenbal Dansran: Writing − original draft, Visualization, Resources, Investigation, Funding acquisition, Formal analysis, Data curation. **Ichinnorov Dashtseren:** Writing − review & editing, Writing − original draft, Supervision, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Garamjav Khishigdavaa:** Resources, Methodology, Investigation, Data curation. **Solongo Bandi:** Validation, Methodology, Investigation, Data curation, Conceptualization. **Byambadolgor Dagviikhorol:** Investigation, Data curation. **Naransukh Damiran:** Methodology, Investigation, Data curation, Conceptualization. **Bayanmunkh Tseden:** Investigation, Data curation. **Bat-Erdene Moyor:** Investigation, Data curation. **Jun-Pyo Myong:** Writing − review & editing, Writing − original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Institutional review board statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Biomedicine Ethics Committee of Mongolian National University of Medical Science, protocol №05, 25/03/2020.

Data availability statement

The data presented in this study are subjects involved in the study.

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Conflicts of interest

All authors declare that there is no conflict of interest.

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Not applicable.

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