GOCE DELCEV
UNIVERSITY

FACULTY OF NATURAL AND
TECHNICAL SCIENCES

NATURAL RESOURCES AND TECHNOLOGY

ISSN: 1857-6966
DOI: 10.46763/NRT

No 2 Volume XIX

DECEMBER 2025

GOCE DELCEV UNIVERSITY – STIP
FACULTY OF NATURAL AND TECHNICAL SCIENCES

Natural Resources and Technology

DECEMBER 2025

VOLUME: XIX NO. 2

ISSN 1857-6966

NATURAL RESOURCES AND TECHNOLOGY

Editorial Office
Goce Delcev University - Stip
Faculty of Natural and Technical Sciences

Contents

Manuscript received: 02.09.2025
Accepted: 28.10.2025

Natural Resources and Technology
Vol 19, No.2, pp. 4 - 9 (2025)
ISSN 1857-6966
UDC: 622.016-051:[614.87:622.411.5]
DOI: https://doi.org/10.46763/NRT2519204m
Original scientific paper

SEASONAL EVALUATION OF WORKERS` PERSONAL EXPOSURE IN UNDERGROUND MINES

Ana Mihailovska[1*], Dejan Mirakovski[1], Marija Hadzi-Nikolova[1], Afrodita Zendelska[1]
Faculty of Natural and Technical Sciences, Goce Delcev University, Stip, North Macedonia,[1]
**Corresponding author: email address ana.mihailovska@ugd.edu.mk*

Abstract
Due to the nature of the underground mining environment, miners frequently face high concentrations of different pollutants. Underground mining is related to several environmental imbalances, including dust, which is recognized as a significant health hazard to mine workers. With a particular focus on mineral dust, lead and silica exposure, this review is intended to determine in which circumstances occupational exposure occurs during various underground activities. The research was conducted in accordance with the General method for sampling and gravimetric analysis of inhalable and respirable dust, as described in MDHS 14/3, HSE - UK, 2000. Measurements were taken twice a year (summer and winter) to evaluate seasonal differences in occupational exposure. The research followed guidelines provided by OSHA PELS as well as those for other pollutants. Seasonal exposures show higher dust during summer while concentrations of lead and crystalline silica remained below the permissible exposure limits in most cases.

Key words: *underground mining, personal exposure, mineral dust, pollutants.*

INTRODUCTION

Several research studies show that mining activities remain the primary source of health-related exposures and are associated with a variety of occupational accidents and diseases [1,2]. Underground mining activities involve significant physical demands, exposure to noise, vibration, radiation, diesel exhaust, elevated temperatures and humidity, as well as contact with dust and hazardous gaseous substances [3,4]. Due to these conditions, miners are continuously exposed to a variety of respirable dust particles generated through mining operations, such as drilling, blasting, and material handling [5]. Despite occupational improvements within the mining industry, each of these operations leads to dust, particularly in situations where effective dust management strategies are not implemented. In addition to seasonal influences, the concentration of dust in underground mines also depends on several other factors, such as the properties of the rocks and minerals, mining methods and equipment, ventilation, humidity and temperature, dust suppression systems, mine geometry and depth, maintenance of equipment, mine layout and traffic, as well as the duration and frequency of operations. The term dust is commonly described as particles that are suspended in the air, typically within a size range of 1 to 100 μm [6]. Those particles contain multiple hazards and their inhalation can lead to a range of effects on respiratory health, such as chronic bronchitis, silicosis, tuberculosis, emphysema, renal failure, and cancer [7]. There is substantial evidence indicating a growing impact of total cumulative dust exposure on breathlessness [8].

Of particular concern within this dust is crystalline silica, a common constituent of mineral formations in lead and zinc mines, a widely recognized occupational hazard. It is found in nearly all mining activities and can lead to numerous health issues, including silicosis among workers and other occupational lung diseases [9,10]. Silicosis is a progressive, irreversible fibrotic lung disease. In addition to these hazards in underground mining environment, lead itself also presents a potential occupational risk to underground workers. Its inhalation can result in a broad spectrum of adverse health outcomes including lead poisoning [11]. Additionally, workers exposed to lead were found having an impairment in respiratory functions with elevated blood lead concentration [12]. The probability of contracting a disease as a result of exposure to mining activities is contingent upon the concentration of inhaled dust, duration of exposure, size of the particles, adequacy of ventilation, and individual characteristics [13].

The investigated mine is located in the north-eastern region of North Macedonia, approximately 150 km east of the capital city, Skopje, and 10 km north of the local town, Makedonska Kamenica. This is an underground mine, of lead and zinc ore, generating close to 750,000 tons of raw ore on an annual basis. This underground mine operates a fleet of nearly 50 diesel-powered vehicles, in addition to various other diesel-powered equipment, culminating in a total installed diesel power of around 3,000 kW.

The research was conducted in two separate phases (winter and summer), where the subject was 10 workers who operated an electro-hydraulic drill and a diesel loader during a full shift of 8 hours of exposure. The methodology was based on the application of general gravimetric analysis, in order to accurately determine the concentration of respirable dust at each of the measuring points. The results obtained allow a clear assessment of the level of exposure of workers and represent a basis for taking measures to protect the health of employees and improve working conditions in underground mines. The measured concentrations were compared with the permissible limit values for mineral dust established by OSHA [14] as well as the guidelines for lead and silica exposure [15, 16].

MATERIALS AND METHODS

As inhalation is usually the most significant route of entry into the body, monitoring the air the miners breathe is vitally important. Air sampling is capturing the contaminant from a known volume of air, measuring the amount of contaminant captured, and expressing it as a concentration. With this in mind, our study seeks to assess the exposure to different underground hazards that miners face in both summer and winter period. There are many different methods of taking air samples, but by far the most common is to use a battery-operated pump to draw a volume of air through a collection device ('sampler') which is mounted in the breathing zone of the worker. The monitoring was employed using gravimetric air samplers over an 8-hour time weighted average period in accordance with general method for sampling and gravimetric analysis of inhalable and respirable dust, MDHS 14/3, HSE - UK, 2000. Target groups were selected with reference to similar exposure groups and their job descriptions. A total of ten miners were included in the two measurement periods – five workers who operated an electro-hydraulic drill (labeled as MP1 – MP5) and five workers who worked as diesel loader operators (MP6 - MP10). Monitoring was conducted using a SKC constant flow pump with cyclone for respirable dust placed within the breathing zone of the miner. Sampling media (Polycarbonate 25 mm filters) were placed inside the head and clipped onto clothing in the breathing zone. A controlled rate of air via the personal sampling pump is drawn through the filter which has been pre-weighed. The filter is weighed after sampling to determine the amount of dust collected. The accuracy of the pump is followed by using a calibrator (rotameter) pre-sampling and post sampling. Following the completion of the gravimetric analysis, additional instrumental approaches were adopted to assess the presence of silica and lead in the dust samples that had been collected.

The concentration of lead was analyzed using NEX CG RIGAKU following the SRM 2783 (National Institute of Standards & Technology, USA), UCDavis (USA) and Micromatter (Canada) certified referent standards, while crystalline silica was determined using the X-ray diffractometer XRD-6100 - Shimadzu, according to the instructions of MDHS101/2 (Crystalline silica in respirable airborne dust Direct-on-filter analyses by X-ray).

The data were obtained following established protocols, which ensured accuracy across all sampling points. The miners were asked to behave like usual, in order to represent suitable exposure during a typical working day. Having in mind that seasonal variation affects underground conditions, measurements taken during two seasonal phases (June and December) were compared to access potential differences that can occur to miners' exposure due to different underground conditions. The process of exposure monitoring generally consists of a series of steps, starting with the installation of sampling devices, followed by the collection of samples, the analysis of those samples, and finally, the interpretation of the data obtained.

Figure 1. IOM sampler positioning

RESULT AND DISCUSSION

After the data had been collected, a comparative analysis was conducted. All operational steps, environmental conditions, and work-related activities were recorded, ensuring transparency, as shown below.

Table 1. Example of a single monitoring point with its measurement period and recorded environmental data

General information					
Code	MP8	Period of sampling			
Activity description		Start		End	
Drilling with an electrohydraulic drill (Horizon 800)		Date	Hour	Date	Hour
		18.06.2024	08:00	18.06.2024	16:00
Method	General method for sampling and gravimetric analysis of inhalable and respirable dust, MDHS 14/3, HSE - UK, 2000				
Filter type	MCE 25 mm	Filter code		MP8	
Microclimatic conditions				Working hours (h)	
Temperature (°C)	Humidity (%)	Pressure (hPa)		8 hours	
/	/	/			
Suspended particles (respirable fraction)				Value	Unit
Measured value (8-hour average)				1.12	[mg/m^3]
Limit value				0,45	[mg/m^3]
Standard measurement uncertainty				± 0,032	[mg/m^3]
Expanded measurement uncertainty				± 0,064	[mg/m^3]
Free silicon dioxide content (SiO_2)				Value	Unit
Measured value (8-hour average)				<0,005*	[mg/m^3]
Limit value				0,1	[mg/m^3]
Standard measurement uncertainty				5	[%]
Expanded measurement uncertainty				10	[%]
Pb concentration (Pb)				Value	Unit
Measured value (8-hour average)				0,003	[mg/m^3]
Limit value				0,05	[mg/m^3]
Standard measurement uncertainty				10,03	[ng/m^3]
Expanded measurement uncertainty				20,07	[ng/m^3]

*Limit of quantification (LQ)

Figure 2 illustrates a comparative analysis of personal dust exposure among the studied workers (MP1-MP10) in both monitoring seasons. Without exception the obtained result demonstrates a lower respirable dust exposure during the winter period. This means that weather conditions affect the underground environment. Most considerable differences are observed at MP1 and MP6. During the summer period, there are exceedances of the permissible limit values for average 8-hour exposure to mineral dust, prescribed by OSHA PELS - Mineral dusts; Table Z-3 of 29 CFR 1910.1000 at 9 out of 10 measurement points. For workplaces where dust limit values are detected to be exceeded, the use of respiratory filters is mandatory. The filter class is defined based on the calculation of the minimum required protection factor. Consequently, for the given purpose, the most suitable is a class 2 dust filter with a minimum protection factor of 12, which can be used up to a maximum dust concentration in the workplace of 5.4 mg/m^3.

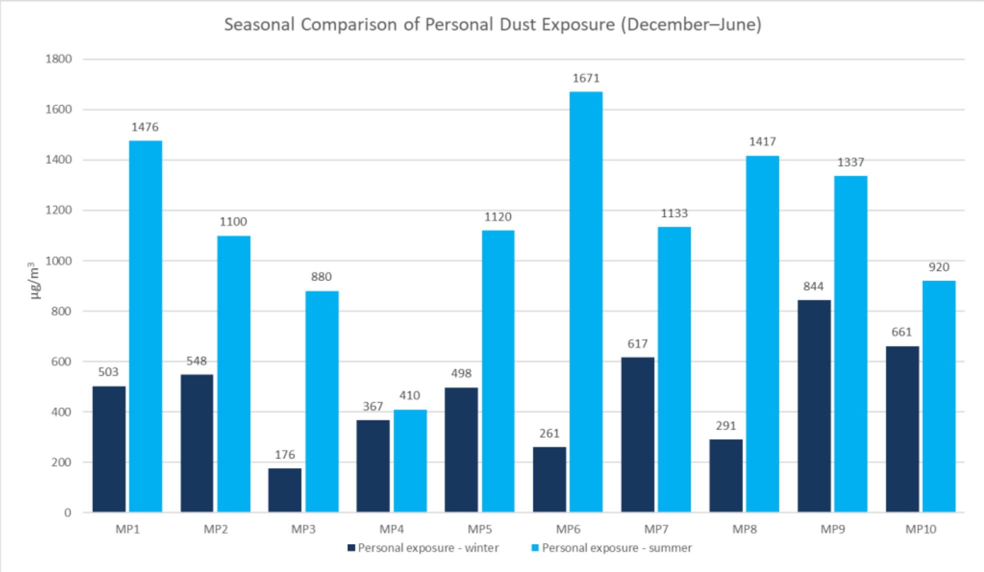

Figure 2. Seasonal comparative analysis of personal exposure to respirable dust fraction (time weighted average, 8-h working shift)

Figure 3 presents the concentrations of lead (Pb) during both monitoring sessions, winter and summer. Across all ten measuring points (MP1–MP10), the concentrations vary from 0.0006 mg/m³ to 0.009 mg/m³. When compared to the limit value of 0.05 mg/m³ for an average 8-hour exposure, the results indicate that lead levels are considerably below the established guidelines, indicating that the observed concentrations do not pose an immediate risk to human health or the environment.

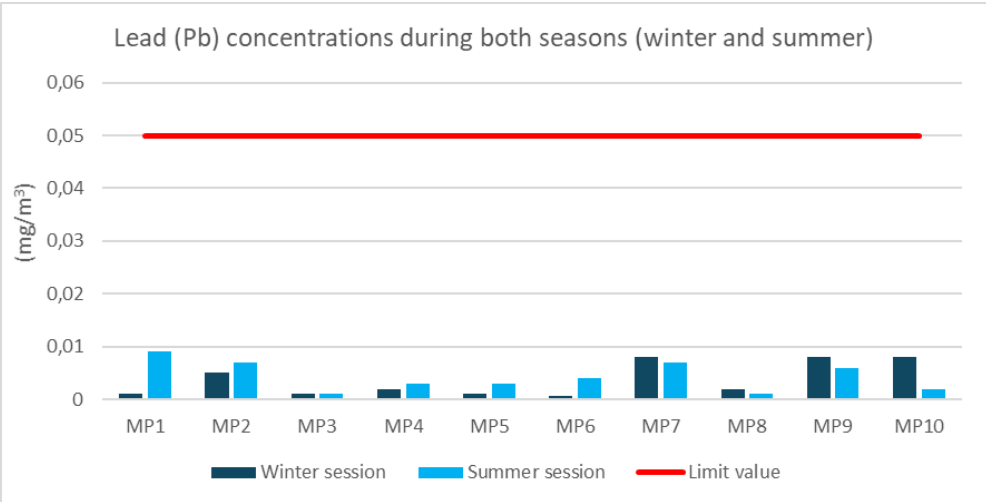

Figure 3. Seasonal comparison of Pb levels in both monitoring seasons (time weighted average, 8-h working shift)

Furthermore, the concentrations of respirable crystalline silica were also assessed during both monitoring periods. The data obtained (Table 2) indicate that the silica concentrations remain significantly below the established occupational exposure limit of 0.1 mg/m³ during both seasonal assessments.

Table. 2 Concentrations of respirable crystalline silica during both monitoring seasons

Measuring point	Summer session (mg/m^3)	Winter session (mg/m^3)	Limit value (mg/m^3)
MP1	0.007 ± 0.001	< 0,005	0,1
MP2	<0.005	< 0,005	0,1
MP3	<0.005	< 0,005	0,1
MP4	<0.005	< 0,005	0,1
MP5	<0.005	< 0,005	0,1
MP6	0.018 ± 0.004	< 0,005	0,1
MP7	<0.005	0,007 ± 0.001	0,1
MP8	<0.005	<0,005	0,1
MP9	0.042 ± 0.011	0,01 ± 0.003	0,1
MP10	<0.005	0,014 ± 0,003	0,1

The highest concentration was observed at MP9, which may indicate localized resuspension of dust particles or site-specific activities that contribute to silica emissions. Overall, the presence of respirable crystalline silica is minimal and remains within the established occupational exposure limits, which suggests that the health risks related to quartz exposure for monitored miners are low under the conditions observed.

CONCLUSION

The results show that the exposure of underground miners to various hazards varies in the seasons. The biggest challenge is mineral dust, which is more prevalent in the summer period. In workplaces where dust limit values have been detected to be exceeded, the use of respiratory filters is mandatory. Lead exposure remains below the permissible limits in both monitoring periods. The presence of crystalline silica is at certain points only and within permissible occupational exposure limits. This underlines the importance of studying miners' exposure to dust and other airborne pollutants.

Occupational Health and Safety (OHS) should remain the top priority in mining. Employers are required to provide a safe work environment and limit their workers' exposure to factors that may be potentially harmful to their health. Monitoring the underground environment is crucial in order to understand impact of underground pollutants on humans and their organisms. This understanding can facilitate the implementation of necessary protective measures and create a safe environment ensuring optimal working conditions.

REFERENCES

1. Gorakhki, M. H., & Bareither, C. A. (2017). Sustainable reuse of mine tailings and waste rock as water-balance covers. Minerals, 7(7), 128. https://doi.org/10.3390/min7070128
2. Ghosh, A.K., Bhattacherjee, A., Chau, N., 2004. Relationships of working conditions and individual characteristics with occupational injuries: a case-control study in coal miners. J. Occup. Health 46, 470–478. 10.1539/joh.46.470
3. Scheepers PTJ, Micka V, Muzyka V, Anzion R, Dahmann D, Poole J, Bos R P (2003) Exposure to dust and particle-associated 1-nitropyrene of drivers of diesel-powered equipment in underground mining. Ann Occup Hyg 47, 379–88. https://pubmed.ncbi.nlm.nih.gov/12855488/
4. Bakke B, Stewart P, Ulvestad B, Eduard W. Dust and gas exposure in tunnel construction work. AIHAJ. 2001 Jul-Aug;62(4):457-65. doi: 10.1080/15298660108984647. PMID: 11549139. https://pubmed.ncbi.nlm.nih.gov/11549139/

5. Rusibamayila, M., Meshi, E. B., & Mamuya, S. (2018). Respiratory impairment and personal respirable dust exposure among the underground and open cast gold miners in Tanzania. Annals of Global Health, 84(3), 419-428. https://doi.org/10.29024/aogh.2323
6. World Health Organization. (1999) . Hazard prevention and control in the work environment: airborne dust. Occupational and Environmental Health Team. https://iris.who.int/handle/10665/66147
7. Cecala, A. B., O'Brien, A. D., Schall, J., Colinet, J. F., Franta, R. J., Schultz, M. J., Haas, E. J., Robinson, J. E., Patts, J., Holen, B. M., Stein, R., Weber, J., Strebel, M., Wilson, L., & Ellis, M. (2019). Dust Control Handbook for Industrial Minerals Mining and Processing (2nd ed.). Centers for Disease Control and Prevention; National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/mining/userfiles/works/pdfs/2019 -124.pdf
8. Bio F, Sadhra S, Jackson C, Burge P. Respiratory symptoms and lung function impairment in underground gold miners in Ghana. Ghana Med J. 2007 Jun;41(2):38-47. doi: 10.4314/gmj.v41i2.55292. PMID: 17925840; PMCID: PMC1976293.
9. Golbabaei, F., Gholami, A., Teimori-Boghsani, G., Yaseri, M., & Kianmehr, M. (2019). Evaluation of occupational exposure to silica dust in mining workers in Eastern Iran. The Open Environmental Research Journal, 12, 1–6. https://doi.org/10.2174/1874213001912010001
10. Sato, T., Shimosato, T., & Klinman, D. M. (2018). Silicosis and lung cancer: Current perspectives. *Lung Cancer: Targets and Therapy, 9*(1), 91–101. https://doi.org/10.2147/LCTT.S156376
11. Needleman, H. (2004). Lead poisoning. Annual Review of Medicine, 55, 209–222. https://doi.org/10.1146/annurev.med.55.091902.103653
12. Jurdziak, M., Gać, P., Martynowicz, H., & Poręba, R. (2015). Function of respiratory system evaluated using selected spirometry parameters in persons occupationally exposed to lead without evident health problems. Environmental Toxicology and Pharmacology, 39(3), 1034–1040. https://doi.org/10.1016/j.etap.2015.03.009
13. Mueller W, Horwell CJ, Apsley A, Steinle S, McPherson S, Cherrie JW, Galea KS. The effectiveness of respiratory protection worn by communities to protect from volcanic ash inhalation. Part I: Filtration efficiency tests. Int J Hyg Environ Health [Internet]. 2018 Jul [cited 2019 Dec 18]; 221(6):967-76. Available from: https://doi.org/10.1016/j.ijheh.2018.03.012
14. OSHA PELS - Mineral dusts; Table Z-3 of 29 CFR 1910.1000. http://www.cdc.gov/niosh/npg/nengapdxc.html
15. Regulation on Minimum Safety and Health Requirements for Workers at Risk from Chemical Substances (Official Gazette of the Republic of Macedonia No. 46/2010), Macedonian language
16. EH40/2005 Workplace exposure limits, HSE Books, Second Edition 2011