Monitoring and Assessment of Airborne Respirable Limestone Dust and Free Silica Content in an Indian Mine

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Introduction

India is ranked second in terms of total worldwide limestone production after China, with 313.2 million tons produced from 2016-17. Limestone is considered the world’s most versatile mineral. India has large limestone resources distributed over different parts of the country. It is an important raw material for various industries, such as the construction industry, steel production, cement manufacturing, etc. Cement and steel have played a crucial role in infrastructure growth in India. From 2016-17, cement grade limestone accounted for 97% of the total limestone production, followed by 2% iron and steel grade and 1% chemical grade. Limestone is a calcareous sedimentary rock mainly composed of carbonates. Calcite and dolomite are the major mineral components of limestone. Limestone frequently contains magnesium carbonate, either as dolomite or magnesite mixed with calcite, becoming ‘dolomitic’ or ‘magnesian’ limestone. Limestone containing a minimum of 45% calcium oxide is generally used in cement manufacture.

Most major mining activities directly or indirectly contribute to air pollution. Operations such as drilling, blasting, crushing, milling, screening, conveying, transporting, etc. are primarily responsible for dust generation in mines. Previous studies have explored the impacts on the immediate environment and health of workers due to mining and processing of limestone. Doig reported eight cases of pneumoconiosis in limestone workers who were involved with crushing and grinding for 16 to 39 years. X-ray and other examination of workers showed symptoms of dyspnoea, cough, sputum, chest pain, asthmatic attack, weight loss, etc. He also concluded that workers involved with the manufacturing and construction industry and mining were more highly exposed to crystalline silica. Koelsch and Kaestle examined 82 workers in a shell limestone mine and concluded that limestone can cause pulmonary changes over a prolonged period under
certain conditions. Gardner reported that calcium carbonate dust can help decrease the toxicity of quartz. Landwehr et al. stated that rocks with greater calcium mineral content are less dangerous and the associated dust is known as ‘protestor dust.’

Silica exposure

Generation of respirable silica dust during mining is a major concern due to its abundance in most mineral work. Millions of workers around the world are exposed to silica dust. Limestone rock contains crystalline silica in different quantities depending upon the type of rock. Limestone contains up to 40% of crystalline silica in some cases. Silica dust exposure occurs more in certain occupations, such as mining, sandblasting, stone cutting, surface drilling, silica flour mill operations, etc. Exposure to silica may decrease resistance to infection by facilitating viral and bacterial contamination through the respiratory tract. Disease severity depends on the amount of crystalline silica in the respirable dust that is deposited in the lungs.

Previous studies provide strong evidence for health problems related to long term airborne silica exposure. For example, Cauda et al. revealed that occupational risk from crystalline silica develops from long term exposure to respirable silica dust which can lead to a potentially fatal lung disease (silicosis). Hnizdo and Vallyathan found that severe silicosis can also cause significant lung impairment. They reported that the risk of developing tuberculosis was greater in workers exposed to silica dust even in the absence of silicosis. Healy et al. studied respirable crystalline silica exposure in a group of stone workers, i.e. stone cutters and stonemasons who work on sandstone, limestone, lime mortar and granite involved in the restoration and maintenance of heritage buildings in Ireland. The results showed that stone workers grinding and cutting sandstone had very high levels of respirable crystalline silica exposure. In cohort studies, Chen et al. found a significant exposure response relationship between silica dust and increased mortality among Chinese workers due to cardiovascular disease, even at low dust concentrations. Yassin et al. also confirmed an association between other health problems due to airborne silica exposure, including chronic bronchitis, chronic obstructive pulmonary disease, lung cancer, airflow obstruction, rheumatoid arthritis, scleroderma, Sjogren's syndrome, lupus, and renal disease.

The present study was undertaken to identify respirable dust concentrations and free silica content in 24 dust samples collected from a limestone mine during pre-monsoon and post-monsoon seasons.

Methods

The present study estimated the exposure of workers by personal dust samplers, evaluated concentrations of respirable dust at the workplace by area monitoring and determined the free silica content in dust samples collected during the study. Lastly, the results were compared with the...
guidelines from the Metalliferous Mines Regulations, 1961 to draw inferences.

Study area

The airborne respirable dust survey was carried out in the east Indian state of Jharkhand. The study area is a well-known open cast limestone mine which manufactures raw material for cement production. It is the only company in India to exploit low-grade limestone for cement manufacture after beneficiation. It is one of largest producing cement mines in India with a production capacity of about 1.8 million tons per annum and a total lease area of 662.75 hectares. The area lies between 22°44'35"N to 22°25'10"N latitude and 85°43'50"E to 85°44'35"E longitude. This region is mainly comprised of rocks of the Kolhan Group, Singhbhum granite, and rocks of the Iron Ore Group. The area where the production and limestone mine is located forms a part of the Chotanagpur Plateau. The limestone belongs to the Kolhan series of the Dharwar age. As mining operations reach the limestone overburden, the underlying Kolhan sandstone is degraded. The limestone varies in color, including off-white, pink, and dark brown.

Mining work is carried out over 24 hours a day in three shifts. Shift A operates between 06:00 am to 02:00 pm, shift B operates between 02:00 pm to 10:00 pm and shift C operates between 10:00 pm to 06:00 pm. There is an additional (overlapping) shift for various administrative and general maintenance work, which operates between 07:30 am to 05:00 pm. The types of mining machinery available at the mine are shown in Table 1.

Sampling

Respirable dust sampling (area and personal sampling) was carried out using a Director General of Mines Safety (DGMS) approved dust sampler, Sidekick 51Ex (SKC, UK), following DGMS sampling guidelines, from February 2014 (pre-monsoon period) to September 2013 (post-monsoon period) at specific locations in the mine. Twelve dust samples were initially collected in September 2013 (5 area samples (AD) and 7 personal samples (PD)), followed by another field study in February 2014 (6 area samples (AD) and 6 personal samples (PD)) at different locations in the mine after consultation with mining

| Serial number | Type of machinery | Capacity (m³) | Number of units |
|---------------|-------------------|--------------|----------------|
| 1             | Shovel            | 3.5          | 2              |
|               |                   | 4.1          | 5              |
| 2             | Drilling machine  | 152          | 4              |
|               |                   | 115          | 1              |
| 3             | Dumper            | 35           | 13             |
|               |                   | 40           | 2              |
| 4             | Dozer             |              | 3              |
| 5             | Backhoe loader    | 3.5          | 2              |

Table 1 — Machinery Available in Mine

| Serial number | Sample ID | Location         | Operation                                      | 8-hour TWA dust concentrations (mg/m³) |
|---------------|-----------|-------------------|-----------------------------------------------|---------------------------------------|
| 1             | PD1       | BC1 to BC2 belt clearing operator | Transfer ore from BC1 to BC2                  | 0.43                                  |
| 2             | PD2       | BC2 to pipe conveyor operator        | Transfer ore from BC2 to pipe conveyor         | 1.04                                  |
| 3             | PD3       | At RL280 bottom pit                  | Shovel Tata Hitachi EX500 operator            | 0.37                                  |
| 4             | PD4       | Bottom pit RL 280                    | Dumper BHEL 210M operator                      | 0.43                                  |
| 5             | PD5       | Pit floor RL 280                     | Shovel Tata Hitachi EX 600, number 7 operator | 0.39                                  |
| 6             | PD6       | Bench Number 1 RL292                 | Drill Copco Flexi ROC D60, helper              | 0.32                                  |
| 7             | PD7       | RL280 to crushe hopper               | Dumper Komatsu HD465 operator, transfer iron ore from RL280 to crushe hopper | 0.40                                  |

Table 2 — Dust Concentration of Personal Dust Samples (n=7) Collected in September 2013

| Abbreviations: PD, personal dust; BC, belt conveyor; RL, reduced level; |
officials. The dust samples for both seasons were collected in A and B shifts for 6-7 hours (355-465 minutes each) during active production phases in the mine. Three area and four personal dust samples in A shift and two area and three personal dust samples in B shift were collected in September 2013. In February 2014, three area and three personal dust samples in A shift and three area and three personal dust samples in B shift were collected. Analysis was performed on all personal and area dust samples collected during both study periods. Sidekick51Ex has a correlation factor of 1.13 with the Mine Research Establishment 113A gravimetric dust sampler (reference sampler). Hence the results obtained by this sampler were divided by 1.13 to get the equivalent Mine Research Establishment concentration in mg/m³.

The sampling assembly consisted of a 37mm cassette filter holding polyvinyl chloride filter paper of 5.0-µm pore, aluminum cyclone and coupler. Each polyvinyl chloride filter paper was pre- and post-weighed on a digital balance (Shimadzu, AW-220). Pre- and post-calibration of Sidekick51Ex samplers was carried out with a DryCal DC-Lite (Bios International, USA) calibrator for a flow rate of 2.2 liters/min. Source monitoring (area sampling) was carried out continuously during the entire working shift during active operations. For area sampling the Sidekick51Ex sampler was kept at a distance of 5 to 15 m away from the workers face and positioned vertically above the ground at breathing level, directed down wind. For personal sampling, the sampler was attached to the worker from the time he entered the mine to the time he left the mine, otherwise known as portal to portal sampling. The Sidekick51Ex was attached to the worker's belt and the cyclone sampler along with cassette was attached to the collar (near the breathing zone) of the worker.

The respirable dust collected on polyvinyl chloride filter paper was also used for estimation of free silica by Fourier transform infrared (FTIR) spectroscopy (Bruker, USA). Sample preparation was done by digesting the collected dust samples in the muffle furnace for four hours at 600°C followed by mixing it thoroughly with potassium bromide (0.2g) in a mortar and pestle. The mixture was transferred to a 13 mm pellet die and the uniform pellets were prepared.

### Table 3 — Dust Concentration of Area Dust Samples (n=5) Collected in September 2013

| Serial number | Sample ID | Area/location | Operation | 8-hour TWA dust concentration (mg/m³) |
|---------------|-----------|---------------|-----------|--------------------------------------|
| 1.            | AD1       | Crusher hopper area | Dumper unloads ore onto crusher hopper | 0.54 |
| 2.            | AD2       | Quarry crusher  | Crushing of limestone | 0.25 |
| 3.            | AD3       | BC2 to pipe conveyor junction | Transfer of limestone from belt conveyor to pipe conveyor | 0.27 |
| 4.            | AD4       | Haul road near view point approaching crusher hopper | Movement of dumpers and other service vehicles | 0.25 |
| 5.            | AD5       | Mine bottom pit haul road junction | Movement of dumpers and other service vehicles | 0.33 |

Abbreviations: AD, area dust; BC, belt conveyor.

### Table 4 — Free Silica Content (%) in Personal Dust Samples Collected in September 2013

| Serial number | Sample ID | Weight of free silica (mg) | Weight of dust (mg) (W2-W1) | Free silica content (%) |
|---------------|-----------|----------------------------|----------------------------|-------------------------|
| 1.            | PD1       | 0.0035                     | 0.54                       | 0.65                    |
| 2.            | PD2       | 0.0059                     | 1.24                       | 0.47                    |
| 3.            | PD3       | 0.0036                     | 0.44                       | 0.82                    |
| 4.            | PD4       | 0.0059                     | 0.51                       | 1.15                    |
| 5.            | PD5       | 0.0042                     | 0.47                       | 0.88                    |
| 6.            | PD6       | 0.0064                     | 0.38                       | 1.68                    |
| 7.            | PD7       | 0.0068                     | 0.48                       | 1.42                    |

Abbreviations: W1, initial weight; W2, final weight; PD, personal dust.
using a hydraulic pellet press. The percentage of free silica was then quantitatively assessed using OPUS software on the FTIR.

Study subjects

The present study was conducted on a total of twenty four male workers (only males were working in the mine, and only 24 miners were available—all consented) engaged with the different heavy earth moving machines (HEMMs) in the mine during both the periods. All workers were aged between 30 and 45. Worker participation was voluntary, and informed consent was obtained.

The study was conducted on the workers after consultation and coordination with the mining officials. This type of air quality sampling is considered part of a miner’s job under occupational hygiene activities. The workers were exposed for 6-7 hours during the active production phase of the mine in Sept. 2013 and Feb. 2014.

Results

The time weighted average (TWA) for dust concentration was calculated in 8-hour shifts and the concentration values (mg/m³) for personal dust samples are given in Table 2.

Table 2 shows the dust exposure of workers at different locations in the mine. The dust exposures of individuals working near belt conveyors were affected due to movement of dumpers in the vicinity. It was observed that 8-hour TW A concentrations of personal respirable dust at all sampled locations were well within the permissible limit (i.e. below 3 mg/m³) as recommended by DGMS. The area of belt conveyor 2 to pipe conveyor operator had the highest dust exposure of 1.04 mg/m³. The TW A dust levels ranged from 0.32 to 1.04 mg/m³.

Table 3 shows the 8-hour TW A dust concentration (mg/m³) for area dust samples collected during different mining operations at their respective locations. It was observed that 8-hour TW A concentrations of personal respirable dust at all sampled locations were well below the permissible limit (i.e. below 3 mg/m³) as recommended by DGMS. The area of belt conveyor 2 to pipe conveyor operator had the highest dust exposure of 1.04 mg/m³. The TW A dust levels ranged from 0.32 to 1.04 mg/m³.

Table 5 — Free Silica Content (%) in Area Dust Samples Collected in September 2013

| Serial number | Sample ID | Weight of free silica (mg) | Weight of dust (mg)(W2-W1) | Free silica content (%) |
|---------------|-----------|-----------------------------|-----------------------------|-------------------------|
| 1.            | AD1       | 0.0068                      | 0.64                        | 1.06                    |
| 2.            | AD2       | 0.0034                      | 0.29                        | 1.18                    |
| 3.            | AD3       | 0.0019                      | 0.32                        | 0.59                    |
| 4.            | AD4       | 0.0020                      | 0.30                        | 0.67                    |
| 5.            | AD5       | 0.0019                      | 0.39                        | 0.49                    |

Abbreviations: W1, initial weight; W2, final weight; AD, area dust.

Table 6 — Dust Concentration of Personal Dust Samples (n=6) Collected in February 2014

| Serial Number | Sample ID | Location | Machine and activity | 8-hour TWA dust concentration (mg/m³) |
|---------------|-----------|----------|----------------------|-------------------------------------|
| 1.            | PD8       | Purple shell, top bench (east side) | L&T Kumatsu, back hoe operator number 1, loading ROM onto tippers | 0.80 |
| 2.            | PD9       | Purple shell, top bench (west side) | L&T Kumatsu, back hoe, number 2 operator, loading overburden onto tippers | 1.04 |
| 3.            | PD10      | Purple green shell, top bench (east side) | Tata Hitachi L&T, number 7 operator | 0.85 |
| 4.            | PD11      | Purple green shell, top bench (east side) | Dumper Komatsu HD465 operator | 0.66 |
| 5.            | PD12      | Purple shell, (south side) | Dumper Komatsu HD465 operator | 0.62 |
| 6.            | PD13      | Safety middle bench | Drill IR -5, CM 260 operator, drilling operation | 1.23 |

Abbreviations: PD, personal dust. ROM, run-of-mine.
Tables 4 and 5 gives the silica content (%) of all respirable dust samples collected in September 2013. Doublet peak characteristic of free silica in FTIR was observed during analysis of all personal and area dust samples. However, the percentages of free silica content in all the dust samples were below 5%. The highest percentage of free silica (1.68%) was observed in ‘Personal Dust 6’ which was the helper operating near the drill machine. This was closely followed by the samples ‘Personal Dust 7’ (1.42%) and ‘Personal Dust 4’ (1.15%) where the operators were engaged in driving dumpers on the haul roads to transport ore from the pit bottom to crusher hopper (Table 4). Likewise, for area dust samples, the maximum was observed in location Area Dust 2 at the quarry crusher with 1.18% of free silica followed by the sample Area Dust 1 at the crusher hopper area (1.06%) (Table 5).

The degree of respirable dust exposure of workers at various locations is shown in Table 6. The 8-hour TWA concentration of all personal respirable dust samples were within the permissible limit (i.e. below 3 mg/m$^3$) as stipulated by the DGMS. The drill operator (Personal Dust 13) at the safety middle bench had the highest dust concentration (1.23 mg/m$^3$), which was close to 50% of the permissible limit (just below 1.5 mg/m$^3$). This was followed by the backhoe operator (Personal Dust 9) working at purple shell top bench (west side) with a dust exposure level of 1.04 mg/m$^3$. The rest of the samples showed dust concentrations below one percent (1%).

The 8-hour TWA dust concentrations (mg/m$^3$) for different locations sampled in the mine are presented in Table 7. Although the 8-hour TWA concentrations at all the sampled locations were within the acceptable limit, the transfer point from crusher belt conveyor 1 to belt conveyor 2 generated a dust level of 2.64 mg/m$^3$ which exceeded 75% of the acceptable limit (i.e. 2.25 mg/m$^3$). Locations ‘Area Dust 11’ (belt conveyor 2 to pipe conveyor junction), and ‘Area Dust 7’ (drilling area at the purple shell top bench) had dust concentrations of 1.52 mg/m$^3$, both of which were above 50% of the acceptable limit (i.e. 1.5 mg/m$^3$). In addition, the loading operation at purple shell top bench in the mine had a dust concentration of 1.42 mg/m$^3$, which was nearly 50% of the acceptable limit. The dust levels observed for the locations at purple shell haul road and the crushing hopper area were 1.14 mg/m$^3$ and 1.04 mg/m$^3$, respectively.

Tables 8 and 9 show the results of the
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free silica content (%) of personal and area dust samples collected in the mine during February 2014. A total of six personal and six area dust samples were qualitatively and quantitatively analyzed for free silica (quartz) at 798 cm\(^{-1}\) wave number by FTIR spectroscopy. Although the typical doublet peak characteristic of free silica was observed for all the personal and area respirable dust samples, the percentage of free silica content was below 5%. Among the workers engaged in various operations, the dust sample of drill operator, ‘Personal Dust 13’, was found to contain the highest percent of free silica i.e. 2.08%. Similarly, samples of dumper operators of Kumatsu (‘Personal Dust 11’) and Kumatsu K2 (‘Personal Dust 12’) had a free silica content of 1.60% and 1.31%, respectively. Across the locations, the highest free silica content was observed in the sample collected at the drilling site (‘Area Dust 7’). The samples from the crusher hopper site (‘Area Dust 9’) and crusher belt conveyor junction (‘Area Dust 10’) had lower silica content, at 1.67% and 0.99%, respectively.

Table 10 presents a comparison of how the silica content/percent varied for area and personal samples and both categories in terms of mean, range, weight of free silica content, sum of actual weight of dust and percent of silica content observed through the pre-monsoon and post-monsoon periods. For September 2013, the total quantity of dust in personal samples (4.06 mg) and personal mean silica content in the dust samples (0.0052 mg) were higher compared to those of area dust samples (1.94 mg and 0.0032 mg, respectively). In addition, the free silica percentage was higher in personal samples compared to area samples. The percentage of free silica content for combined (personal and area) samples was 0.87%, which can be considered to be a representative figure for the entire mine.

For the samples collected during February 2014, the free silica percent analyzed in personal samples was much greater than area samples. The percent of free silica content for all samples combined was found to be 1.73%.

Table 11 summarizes and evaluates dust concentrations in terms of minimum, maximum, average, and concentrations at ≥50% and ≥75% of permissible limits from the results of monitoring in September 2013 (7 personal and 5 area dust samples) and February 2014 (6 personal and 6 area respirable dust samples). Operators at various locations in the mine were working with a personal dust exposure range between 0.32–1.04 mg/m\(^3\) with an average concentration of 0.48 mg/m\(^3\) in September 2013, and 0.62–1.23 mg/m\(^3\) with an average of 0.87 mg/m\(^3\) in February 2014.
workers were exposed to higher dust concentrations in February 2014 compared to September 2013. The dust survey through February 2014 revealed that one worker and three area locations were found to have dust concentrations above 50% of the permissible limit and dust concentrations exceeded 75% of the limit prescribed by the DGMS in one location.

Figure 2 and 3 illustrate the exposure of miners with respirable dust concentrations in various sites in the mine in September 2013 and February 2014, respectively.

Discussion

The weather in the month of September 2013 in the mine was temperate and dry. The presence of moisture in the atmosphere after the rainy season suppressed dust levels. The calculated TWA for an 8-hour shift in the workplace for personal and area samples in the mine was below the prescribed limit of 3 mg/m³ as recommended by DGMS (Tables 2 and 3). The September 2013 sampling was conducted just after the rainy season, which could be the reason for low dust concentrations (Tables 2 and 3). Based on the results, the operating area for transferring ore at belt conveyor 2 to the pipe conveyor had the highest dust levels compared to all other personal monitoring stations (Table 2). Additionally, the crusher hopper area had the highest dust levels compared to all other monitoring stations (Table 3).

Dust concentrations were much higher for the majority of personal and area monitoring stations when re-evaluated during the pre-monsoon period in February 2014. In an earlier study, exposure to dust was linked to crushing and drilling operations, which were the activities with the highest dust production, resulting in a significant increase of dust levels in the mine.¹³ As seen from the samples collected in February 2014, the operator of the drilling machine (‘Personal Dust 13’) was found to be more highly exposed to dust compared to others in the mine (Table 6). Workers engaged with loading operation tasks (‘Personal Dust 9’) had significant dust exposure, although below permissible limits (Table 6). In the examination of area locations, the highest dust exposure (>75% of acceptable limit) was seen at the crusher belt conveyor junction (belt conveyor 1 to belt conveyor 2) (Table 7). While fewer workers were needed at the belt area of the crusher conveyor, efforts should be made to reduce the airborne respirable dust concentration at this location. Although the TWA dust concentration at none of the monitoring stations exceeded the permissible limit (3 mg/m³) throughout the monitoring period, the probability of exposed

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| Duration      | Samples  | Number | Minimum (mg/m³) | Maximum (mg/m³) | Average (mg/m³) | Number and concentration of dust samples ≥ 50% | Number and concentration of dust samples ≥ 75% |
|---------------|----------|--------|-----------------|-----------------|-----------------|-----------------------------------------------|-----------------------------------------------|
| September 2013| Personal | 7      | 0.32            | 1.04            | 0.48            | 0                                             | 0                                             |
|               | Area     | 5      | 0.25            | 0.54            | 0.33            | 0                                             | 0                                             |
| February 2014 | Personal | 6      | 0.62            | 1.23            | 0.87            | n=1                                           | 0                                             |
|               | Area     | 6      | 1.04            | 2.64            | 1.55            | n=3                                           | 1.23 mg/m³, 1.42 mg/m³, 1.52 mg/m³, 1.52 mg/m³ |

Table 11 — Respirable Dust Concentration (mg/m³) in Personal and Area Samples During September 2013 and February 2014

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Abbreviations: PD, personal dust; AD, area dust.

Figure 2 — Personal and Area Dust Exposure Monitoring During September 2013
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The findings of this study may be applied to other similar mines and industries in India and abroad to evaluate dust and free silica exposure risk factors in order to improve work environments.

Conclusions

The objectives of the present study were to assess respirable dust concentrations in major working areas, personal dust exposure and associated occupational health risks, and free silica content across seasons in an Indian mine. The study was limited to 24 dust samples. A more complete picture may be available with a larger scale study. The 8-hour TWA concentrations of airborne respirable dust in all of the sampled locations for the study conducted in September 2013 and February 2014 were within the limits prescribed by DGMS (3 mg/m$^3$). Although all TWA dust concentrations were below 3 mg/m$^3$, at some monitoring stations the concentrations exceeded 50% and 75% of the stipulated limit. Dust concentrations at most of the monitoring stations reached a maximum during the pre-monsoon period and were lower in the post-monsoon period. The operations at the crusher belt conveyor junction, blasting, drilling, loading, shoveling and transportation areas were found to have the highest dust levels of all mining operations. The operator near the crusher belt conveyor junction (crusher belt 1 to crusher belt 2) had a greater risk of dust exposure. Drill, dumper, and shovel operators were also found to be more highly exposed during active mining operations. During respirable dust sampling, the crusher plant and mining operation were not active for the full 8-hour shift and the respirable dust TWA average level may not be a representative sample. The free silica content in all of the samples screened during the study
period was found to be less than 5% of the permissible limit. However, the exposure of a large number of workers to crystalline silica suggests that further work is needed to develop best practices and strict maintenance to protect workers from the risk of silica exposure.

Prolonged exposure to dust can lead to respiratory disease and serious health problems such as pneumoconiosis, dermatitis, irritation and inflammatory lung injuries, occupational asthma, etc. Safety management along with quantitative assessment of dust exposure can play an important role in reducing dust concentrations at vulnerable sites. Mine officials should implement control measures and monitor airborne respirable dust in the mine. These continued efforts can lead to more eco-friendly mining and a better work environment for all workers in the area.

Acknowledgements
The authors are grateful to the Director of the National Institute of Miners’ Health, Nagpur (India) for providing all necessary facilities and guidance to conduct the research as well as granting permission for publication of this research article. This study was funded by the National Institute of Miners’ Health, Nagpur.

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