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ORIGINAL ARTICLE

Assessment of Respiratory Symptoms among Sandstone Workers Associated with Respirable Dust and Fine Particulate Matter (PM2.5) Exposure

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ABSTRACT

Introduction: Sandstone workers were exposed to dust generated during processing. This research aimed to determine the concentrations of respirable dust (RD) and fine particulate matter (PM2.5), as well as to assess respiratory symptoms and associated factors. **Methods:** A cross-sectional study was conducted among 140 sandstone workers in northeastern Thailand. Personal dust samples were collected throughout the shift in accordance with NIOSH 0600 and EPA IP-10A. The dust concentrations were analysed by the gravimetric method. Face-to-face interviews were conducted using a questionnaire to assess demographic data and respiratory symptoms. **Results:** The mean concentration of RD and PM2.5 found in sandstone cutting was 0.48 and 0.25 mg/m3, while it was seen to be lower among sandstone chiselling (0.14 and 0.07 mg/m3). At least one respiratory symptom was reported by 57% of the workers. The most common symptom was phlegm (49.3%). Work experience and not wearing a mask while working were factors significantly associated with respiratory symptoms (p-values 0.018 and 0.014, respectively). Work experiences 6 -10 years and > 10 years, and not wearing masks had a chance of developing respiratory symptoms (OR=2.64, 2.73, and 2.73). **Conclusion:** PM2.5 accounted for half of the RD released during sandstone processing. Phlegm and dry cough were the most common symptoms among exposed workers. The workers should be advised to improve the working conditions and to use the appropriate masks. The local health authorities should establish routine monitoring of the working environment and an annual training course on dust prevention for workers.

Keywords: PM2.5, respirable dust, respiratory symptoms, sandstone workers, sandstone processing

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INTRODUCTION

Dust in the working environment is a major concern due to its negative health effects on workers in various stone factories, including sandstone processing. Sandstone processing uses natural sandstone as a raw material to produce exterior home decorations, including Buddha statues, elephant statues, and decorative stone walls. Sandstone dust contains a wide range of natural minerals, including silica, calcite, feldspar, micas, and clay minerals (Hall *et al*., 2022). Inhalation of dust containing crystalline silica is a well-established hazard across a variety of stone industries, including mining, masonry, carving, stone grinding, mortar making, and sandstone factories (Sahri and Sunaryo, 2020). Typically, sandstone processing production generates respirable dust (RD) and particulate matter less than 2.5 micrometres in diameter (PM2.5) that are emitted into the atmosphere (Wippich *et al*., 2020). If workers inhaled the tiny particles, they could penetrate deeply into the lower respiratory tract, which leads to acute and chronic respiratory diseases (Nti *et al*., 2020; Vlahovich and Sood, 2021; Ahmed *et al*., 2022; Susanto *et al*., 2024). Interestingly, PM2.5 is more dangerous than RD, because it can penetrate deeper into the respiratory system.

The size, concentration, form, solubility, chemical properties, and duration of exposure of particles are among the factors that influence the development of respiratory symptoms. The development of respiratory symptoms is also greatly influenced by individual factors, including immunology, respiratory tract anatomy and physiology, and lung mechanical systems (Susanto *et al*., 2024). Previous research has shown that short- and long-term exposure to dust in mining industries

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and stone factories can cause eye, nose, throat, and skin irritation, respiratory symptoms, and an increased risk of occupational lung diseases (Lestari *et al*., 2023). Several studies investigated respiratory symptoms and occupational lung diseases associated with dust exposure in various stone factories using questionnaires. The findings indicated that shortness of breath, phlegm, and cough were common signs of respiratory symptoms among artisanal sandstone (Souza, van Tongeren and Monteiro, 2021); chronic cough, chest pain, shortness of breath, and wheezing were explored as respiratory symptoms among current and ex-stone mining workers (Alagarajan and Ahmad, 2022).

Sandstone processing industries are mostly located in rural areas due to the abundance of material and unique geology. In northeastern Thailand, many cottage industries are known for producing sandstone objects in Nongenomic and Klongphai Sub-Districts, Sikhio District, Nakhon Ratchasima Province. The production of sandstone processing consists of 2 tasks, namely1) stone cutting at home;the workers used the motorized cutters such as electric cutters to cut the big sandstone into small pieces before passing them to the forming process; and 2) sandstone chiseling; the workers used hand tools, like chisels, large nails, and hammers for percussing smaller pieces of sandstone into the desired forms and pattens for sandstone objects. The workers perform individual tasks in the same environment. When utilising equipment, e.g., motorised equipment and hand tools, airborne particles can be generated in the working environment. In this regard, workers handle their tasks using a wetting system to control dust.

As mentioned, many previous studies have focused on RD exposure and respiratory symptoms. Leading to our interest in assessing workers' respiratory symptoms related to particulate matter in sandstone processing facilities, with particular emphasis on two particle sizes: RD and PM2.5. Therefore, the purposes of this study were to determine concentrations of RD and PM2.5 in the work environment and to assess respiratory symptoms and factors associated with respiratory symptoms among exposed sandstone workers.

METHODS

A cross-sectional study was conducted among 140 sandstone workers from sandstone processing facilities in two sub-districts of Sikhio District, Thailand, from September to October 2023. The sample size was calculated by using a finite population formula based on the main prevalence of respiratory symptoms among artisanal mine workers at 25% (Souza, van Tongeren and Monteiro, 2021). Stratified sampling was applied to estimate the required sample size in each Sub-District. Then,the convenience sampling technique was used to recruit participants for the study. Inclusion criteria were male and female workers aged 18-59 years who had been working at home in sandstone processing for at least 1 year and who were able to communicate in Thai. The sandstone workers had a history of chronic respiratory problems, and respiratory symptoms of long COVID-19 were excluded from this study. The research objectives and participants' rights were clearly explained, and the consent form was signed prior to data collection. The study protocol was approved by the Human Research Ethics Committee of Thammasat University (Science), with COA No. 029/2566.

The participants were interviewed face-to-face using a questionnaire. The questionnaire was divided into two parts. The first part included questions regarding demographic characteristics: age, gender, education level, smoking history, working day (hour/day), work experience (years), underlying diseases, and respiratory protective equipment, including types of respiratory protective equipment and masks used while working. The second part included a question on respiratory symptoms, based on the British Medical Research Council (BMRC) standardised questionnaire (1960). The questions consisted of five symptoms, namely dry cough, phlegm, chest tightness, breathing difficulty, and wheezing. Reliability was assessed using Cronbach's alpha, yielding a coefficient of 0.85. The interpretation of respiratory symptoms was defined as yes/no. If participants answered "yes" to at least one question in each symptom item, it was considered to have respiratory symptoms.

The personal dust samples were collected into two dust fractions, namely RD and PM2.5, for each task performed by the sandstone workers. The RD samples were collected by using a personal air sampling pump connected with an aluminium cyclone with a filter cassette containing a 37 mm diameter, 5.0 μm pore-size Polyvinyl Chloride filter (PVC) using a flow rate of 2.5 litres per minute, according to NIOSH method 0600(National Institute on Occupational Safety and Health (NIOSH), 1998). The PM2.5 samples were collected using a

Table 1. Participants' characteristics (n= 140)

Characteristics	Number	%
Age (years)		
19-29	28	20.0
30-39	36	25.7
40-49	49	35.0
50-59	27	19.3
Mean ± SD = 39.3 ±10.9 years min-max = 19-59 years		
Gender		
Male	89	63.6
Female	51	36.4
Education level		
Unschooled	16	11.4
Primary school	93	66.4
Secondary school	10	7.2
Higher secondary school	21	15.0
Smoking		
No	65	46.4
Yes	75	53.6
Number of cigarettes/tobaccos smoking per day (roll)		
< 5	76	54.3
6-10	34	24.3
11-15	4	2.8
+16	26	18.6
Smoking history (years)		
1-5	22	15.7
6-10	24	17.2
+11	29	20.7
Mean ± SD = 6.5 ± 8.5 years min-max = 1-31 years		
Sandstone processing process		
Cutting at home	80	57.1
Chiseling	60	42.9
Work experienced (years)		
1-5	58	41.4
6-10	33	23.5
11-15	23	16.5
+16	26	18.6
Mean ± SD = 9.7 ± 7.5 years min-max = 1-36 years		
RPE used during work		
No	71	50.7
Yes	69	49.3
Type of RPE		
Cotton mask	65	46.4
Surgical mask	36	25.7
Loincloth or/and shirt	25	17.9

SD = Standard Deviation

personal environmental monitor (PEM) impactor with a 37 mm diameter and a 5.0 µm pore-size PVC membrane filter, operated at a flow rate of 4 litres per minute, according to EPA IP-10A (US.EPA, 2004). Both RD and PM2.5 samples were mounted on a worker's cloth collar in the breathing zone during normal working hours, for about 6 to 8 hours. The personal air sampling pump was calibrated to the desired flow rates by using the Dry Cal Defender 500 series. Field blanks were performed in the same condition. All dust samples were analysed by the gravimetric method. Before weighing, all filters were equilibrated in a desiccator for 2 hours. Field blanks were performed in the same condition. The filter samples and filter blanks were weighed using an electronic analytical balance with a sensitivity of 0.001 mg (Mettler Toledo MT5, USA), and the reported concentrations were expressed in mg/m3.

Statistical analysis was performed using the Statistical Package for Social Sciences® (SPSS) version 23. Descriptive statistics were used to assess the respiratory symptoms, demographic data, and the RD and PM2.5 concentrations. The data are presented as frequencies, percentages, and mean ± standard deviation (SD). Chi-square was used to test for bivariate associations, and binary logistic regression was used to analyse the chance of developing respiratory symptoms. A p-value less than 0.05 was considered statistically significant.

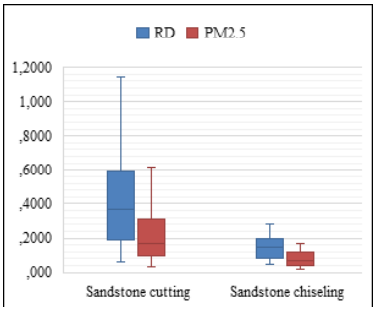

Figure 1. Box plot of RD and PM2.5 concentrations by tasks

Table 2. Concentration of RD and PM2.5

Tasks	Dust concentration in mg/m3				Ratio of PM2.5/ RD
	RD (n = 70)		PM2.5 (n = 70)		
	Mean±SD	Min-Max	Mean±SD	Min-Max	
Sandstone cutting	0.48±0.35	0.06-1.14	0.25±0.18	0.03-0.62	0.52
Sandstone chiseling	0.14±0.06	0.05-0.28	0.07±0.04	0.02-0.17	0.50

SD = Standard Deviation

RESULTS

Participant characteristics

A total of 140 participants were included in the study; sandstone workers were male (63.6%) and female (36.4%), with an average age of 39.3 ± 10.9 years. Most of them finished primary school, 66.4%. They had been categorised into two tasks: sandstone cutting workers (57.1%) and sandstone chiselling workers (42.9%). The average work experience was 9.7±7.5 years, and most had more than 5 years (59.6%). Most of the participants had a history of smoking (53.6%) and no smoking (46.4%). About half of the workers (50.7%) reported not wearing masks at work. For respiratory protective equipment (RPE) used during work, cotton masks (49%), loincloths or shirts (27%), and surgical masks (24%). The participants' demographic characteristics are demonstrated in Table 1.

Concentrations of RD and PM2.5

Two sizes of dust samples, RD and PM2.5, were collected using personal air samplers in the breathing zone. Each personal dust sample was collected simultaneously over the full shift. Overall, the mean concentrations of RD and PM2.5 were 0.32±0.31 mg/m3 (range: 0.05-1.14 mg/m3) and 0.17±0.16 mg/m3 (range: 0.02-0.62 mg/m3), respectively. The mean concentration of RD and PM2.5 in sandstone cutting was 0.48±0.35 mg/m3 and 0.25±0.18 mg/m3. For sandstone chiselling, the mean concentrations of RD and PM2.5

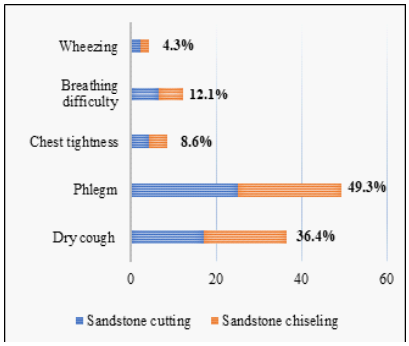

Figure 2. Respiratory symptoms among sandstone workers (n =140)

were 0.14±0.06 mg/m3 and 0.07±0.04 mg/m3, respectively. Interestingly, the average concentration ratios between PM2.5 and RD during sandstone cutting and sandstone chiselling were 0.52 and 0.50, respectively. However, the concentration of RD in both sandstone cutting and sandstone chiselling did not exceed occupational exposure limits by the OSHA (5 mg/m3) (OSHA, 2025) and the ACGIH recommendations(3 mg/m3) (ACGIH, 2025). Currently, there are no workplace exposure standards or recommendations for PM2.5. The results of RD and PM2.5 concentration in sandstone processing were presented in Table 2 and Figure 1.

Respiratory symptoms of sandstone workers and associated factors

Fifty-seven per cent of the sandstone workers had at least one respiratory symptom. Overall, the findings showed that phlegm was the predominant respiratory symptom (49.3%), followed by dry cough (36.4%), breathing difficulty (12.1%), chest tightness (8.6%), and wheezing (4.3%), respectively. Based on the tasks performed, the results revealed similar trends in the percentage of respiratory symptoms as presented in Figure 2. Considering factors associated with respiratory symptoms, there were significant associations with work experience (p-value = 0.018) and wearing a mask at work (p-value = 0.014), as shown in Table 3.

Considering the chance of developing respiratory symptoms, compared with work experience 1-5 years, workers who had work experience 6-10 years had a chance of 2.64 times (95% CI: 1.08-6.44, p-value = 0.033) and work experience of more than 11 years had a chance of 2.73 times (95% CI: 1.23-6.01, p-value = 0.013). Moreover, workers who did not wear masks while working had a 2.73 times greater risk of developing respiratory symptoms than those who wore masks all the time (95% CI: 1.37-5.45, p-value = 0.004), as shown in Table 4.

DISCUSSION

Sandstone processing in Sikhio District, Nakhon Ratchasima Province, Thailand, is recognised for its prominent production of sandstone objects. This area was reported to be among the top 10 provinces with the highest incidence of silicosis (Ministry of Public Health Thailand, 2022). Due to an abundance of sandstone, many household industries have emerged. Leading to the target area of this study, the results lead to the following discussion:

Sandstone workers in sandstone cutting are exposed to higher concentrations of RD and PM2.5 than those in sandstone chiselling. The finding is similar to previous studies conducted among Indian stone mine workers (Prajapati *et al*., 2020) and Indonesian stone clay workers in the ceramics industry (Sahri and Sunaryo, 2020). The large number of tiny particles is dispersed when workers cut the sandstone with a motorised saw. Sandstone cutting involves using electric cutters to

Table 3. Factors associated with respiratory symptoms among sandstone workers (n=140)

Variables	Respiratory symptoms		x^2	p-value
	Yes, n (%)	No, n (%)		
Gender			0.165	0.820
Male	52 (58.4)	37 (41.6)		
Female	28 (54.9)	23 (45.1)		
Age (years)			0.10	1.000
<40	42 (56.8)	32 (43.2)		
≥40	38 (57.6)	28 (42.4)		
Smoking			0.538	0.574
No	35 (53.8)	30 (46.2)		
Yes	45 (60.0)	30 (40.0)		
Work experience (years)			7.984	0.018*
1-5	25 (43.1)	33 (56.9)		
6-10	22 (66.7)	11 (33.3)		
≥11	33 (67.3)	16 (32.7)		
Wearing mask while working			8.388	0.014*
No	49 (69.0)	22 (31.0)		
Yes	31 (45.0)	38 (55.0)		
RD levels			0.556	0.456
Low (<0.32 mg/m3)	54 (55.1)	44 (41.9)		
High (≥0.32 mg/m3)	26 (61.9)	16 (38.1)		
PM2.5 levels			0.750	0.784
Low (<0.17 mg/m3)	59 (57.8)	43 (42.2)		
High (≥0.17 mg/m3)	21 (55.3)	17 (44.7)		

* Significant at p-value < 0.05

break the rock into many small sandstone pieces. Therefore, large amounts of small particulate matter are released into the atmosphere (Thompson and Qi, 2023). Workers are likely to be exposed to higher dust concentrations when cutting stone than in other tasks, posing a significant respiratory health risk (Hall *et al*., 2022). Whereas sandstone chiselling is performed with hand-held power tools and uses smaller stone pieces than sandstone cutting. However, both tasks are conducted using the wet system to control dust dispersed into the atmosphere.

Based on dust proportions, the average PM2.5 concentration accounted for approximately 50% of RD. It can imply that large amounts of fine particles were generated from sandstone processing. This is a case that should be taken into consideration because the particles, which range in size from 0.5 to 4 microns, are easily inhaled during normal breathing and can reach the alveoli. The PM2.5-to-RD ratio provides important evidence for assessing dustiness in the working environment of sandstone processing (Wippich *et al*., 2020). This study reveals that the highest average exposure concentration of PM2.5 over the entire working period is 250 μg/m³ (0.25 mg/m³), which is 17 times higher than the 24-hour global standard regulated by the World Health Organisation (15 μg/m³) and 7 times higher than the Thai standard (37.5 μg/m³). The dispersion of dust in the working environment exposes workers directly to PM2.5 due to the use of electric saws during cutting tasks (Hall *et al*., 2022; Thompson and Qi, 2023). Although there is currently no standard value for PM2.5 during normal working hours, this information may be used for sandstone workers' exposure monitoring, as PM2.5 is harmful to the respiratory system (Hu *et al*., 2023; Krittanawong *et al*., 2023). When workers inhale tiny dust particles, it can cause adverse health effects across many systems, including the respiratory system. In addition, fine particles increase the risk of ischaemic heart disease (IHD) and stroke, which increases the morbidity and mortality rates of respiratory diseases, cardiovascular diseases, and chronic obstructive pulmonary disease (COPD) (Hayes *et al*., 2020; Mebrahtu *et al*., 2023; Wan Mahiyuddin *et al*., 2023). This rate increases with ambient PM2.5 concentration (Sukuman *et al*., 2023).

The results of this study revealed that the most common respiratory symptom among exposed sandstone processing workers is phlegm, while wheezing is the least common. This finding is similar to findings from previous studies across various stone industries. Dust less than 10 microns in diameter can enter the respiratory tract and irritate the mucous membranes, leading to respiratory symptoms such as dyspnoea, sneezing, coughing, wheezing, sputum, and chest pain (Souza, van Tongeren and Monteiro, 2021). Possible reasons for the high prevalence of respiratory symptoms include poor ventilation systems, inadequate use of respiratory protective equipment, and workers' lack of awareness of the dangers of exposure to respirable particulate matter (Ahmed *et al*., 2022). This is also found in this study.

In this study, factors significantly associated with respiratory symptoms among workers in sandstone processing are similar to those in previous studies. 10 years of work experience among stone mine workers was associated with respiratory problems (Dhatrak and Nandi, 2020; Ahmed *et al*., 2022). The use of RPE is found to be neglected by workers, and it was inappropriate against both RD and PM.25. In this situation, it will promote tiny particles to pass into the respiratory tract. As a result, workers are at a higher risk of developing respiratory symptoms and other occupational lung diseases (Ashuro *et al*., 2023).

In our study, in addition to improper use of RPE, we observed poor working conditions and a lack of the latest technologies and proper exhaust systems, which allow many particles to enter the

Table 4. The association factors with respiratory symptoms among sandstone workers (binary logistic regression) (n=140)

Variables	Respiratory symptoms		OR ratio	95% CI	p-value
	Yes, n (%)	No, n (%)			
Work experience (years)					
1-5	25 (43.1)	33 (56.9)	1		
6-10	22 (66.7)	11 (33.3)	2.64	1.08-6.44	0.033*
≥11	33 (67.3)	16 (32.7)	2.73	1.23-6.01	0.013*
Wearing mask while working					
Yes	31 (45.0)	38 (55.0)	1		
No	49 (69.0)	22 (31.0)	2.73	1.37-5.45	0.004*

* Significant at p-value < 0.05

working environment. These could be variables that harm the respiratory health of sandstone workers. However, it would be better to conduct a further study focusing on determining respirable crystalline silica (RCS) since silica is the cause of silicosis. Consequently, this is a drawback in this study. Nevertheless, this study is likely to be the first to describe the proportion of PM2.5/RD in household sandstone processing, where information on these informal workers remains limited and warrants government attention. The valuable data from this study serve as the basis for an evaluation, providing recommendations on control measures to protect workers in dusty work environments for local health sectors.

CONCLUSION

More than half of the sandstone workers report respiratory symptoms. Phlegm and a dry cough are the most common symptoms. During sandstone processing, RD and PM2.5 are generated, with half of the RD levels composed of PM2.5, and no significant difference in concentration between stone cutting and stone chiselling. The absence of appropriate respiratory protective equipment and having more than 10 years of work experience are significantly associated with respiratory symptoms. Based on the results, to prevent exposure to sandstone dust and the development of respiratory symptoms among workers, routine monitoring of the working environment, providing knowledge on sandstone dust prevention, and encouraging workers to self-screen for respiratory symptoms with local health authorities are recommended. Simultaneously, the workers should be advised to use appropriate masks that match the characteristics of the dust generated by their work.

CONFLICT OF INTEREST

The authors declare that there are no significant competing financial, professional, or personal interests that might have affected the performance.

AUTHORS' CONTRIBUTION

WC: Conceptualisation, Data collection, Methodology, Visualisation, and Writing-Original draft preparation. LL: Investigation, Writing-Reviewing, and Editing.

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