RESEARCH ARTICLE

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Application of Multiple Occupational Health Risk Assessment Models for Crystalline Silica Dust among Stone Carvers

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Abstract

Objective: Silica is the most abundant substance on the Earth's crust and is a proven carcinogen. The aim of this study was to measure the occupational exposure of stone carvers to crystalline silica and to evaluate the health risks. **Methods:** This descriptive and analytical cross-sectional study was performed on 79 stone carvers. Inhalation air sampling was performed by the NIOSH7500 method and the amount of silica was determined by X-ray diffraction (XRD). Semi-quantitative and quantitative risk assessments were performed using the methods of the Singapore Department and the US Environmental Protection Agency (EPA), respectively. Mortality due to silicosis and lung cancer were estimated using the Manettej and Rice models. Data were analyzed using SPSS23 software. **Results:** The mean exposure to total inhalable dust and crystalline silica among the stone carvers was 1.44 and 0.5 mg/m3, respectively. Exposure to total dust and silica was significantly higher than the occupational standard ($P < 0.0001$). Stone carvers' exposure to silica was at very high-risk level, and the carcinogenicity of silica considering two cancer slopes was 7.40 × 10-6 and 3.12×10^{-7} and the risk of non-carcinogenicity was unacceptable. **Conclusion:** The mortality rate due to silicosis was between 3 and 12 people per thousand, and due to lung cancer was 150.24 people per thousand. Based on the results of risk assessment, serious control measures should be implemented in order to reduce workers' exposure to silica.

Keywords: Silica exposure- X-ray diffraction- stone carvers- risk assessment- lung cancer- silicosis mortality

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Introduction

Silica is considered as one of the most important minerals used in various industries around the world. Crystalline silica exists in three forms including quartz, cristobalite and tridymite in nature; and quartz is the most common form (Moradpour and Jarrahi, 2023; Azari et al., 2009). In 1997, the International Agency for Research on Cancer (IARC) classified crystalline silica in Group 1 as a definitive carcinogen for humans based on sufficient evidence of carcinogenicity (Steenland et al., 2001). Occupational exposure to crystalline silica also causes diseases such as kidney disease, immune system problems, chronic bronchitis, emphysema, silicosis and lung cancer (Alicandro et al., 2020). Workers in a variety of industries such as foundry (Andersson et al., 2023), construction (Kakoei et al., 2014), tile (Nourmohammadi et al., 2022), sandblasting (Kakoei et al., 2014) and concrete (Mehta and Ashish, 2020) industries are exposed to dust from crystalline silica particles, which can seriously endanger their health Silicosis is one of the most debilitating lung diseases in the world, which causes premature death due to secondary diseases such as pulmonary tuberculosis, chronic obstructive pulmonary disease, and heart and lung diseases (Keramydas et al., 2020). Exposure to silica particles occurs in occupations such as stone carvers, granite workers, miners, asphalt workers, sanders, ceramic workers, and workers working in cement factories (Rahimi Moghadam et al., 2020). One of the most important jobs that workers are exposed to silica is masonry. In this profession, prolonged and frequent exposure to silica dust particles below 10 microns in the workplace can cause inflammation and fibrosis in the lung tissue, and a potentially fatal disease called silicosis. Since silicosis is an incurable but preventable disease (Nourmohammadi et al., 2022), awareness of the quantitative and qualitative status of crystalline silica dust in the respiratory air of the workplace is of special importance in order to suggest effective ways for prevention, control and minimizing adverse effects (Thomas and Kelley, 2010). In recent years, risk assessment has become one of the most important topics in the control of occupational diseases. In risk

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assessment not only the toxicity or side effects, but also the mortality risk from exposure to risk factors is estimated (Jebelli et al., 2015). Azari et al., (2009) conducted a risk assessment of workers exposed to ambient silica dust in eastern Tehran. In this study, the geometric mean of exposure to ambient silica in 10 different industries was between 0.132 to 0.343 mg/m^3, and the death rate due to silicosis was predicted to be between 1 to 52 per thousand, and the risk of death from lung cancer in workers exposed after 45 years of exposure was 50-129 per thousand. Another study by Kakoei, et al., (2014) was carried out on demolition sites in Tehran. In this study, the exposure of workers to crystalline silica was in the range of 0.085-0.185 mg/m^3 and the relative risk of death from silicosis was between 1-22 people, and the risk of death from lung cancer was 32 -60 people per thousand .In a cohort study conducted by Liu et al the risk of cancer mortality from silica exposure was determined among 34,000 workers working for 44 years. In this population, 546 deaths happened due to lung cancer (Chen et al., 2012). In the past, studies about silica exposure were more about measuring exposure and documenting the hazardous effects of silica, whereas recently many studies try to predict mortality and hazardous effects before their occurrence, in order to attract attention towards controlling the harmful exposure levels. In these studies, different models have been used, such as the Manettej model that predicts mortality related to silica, and the Rice model that predicts the incidence of silicon-induced lung cancer over a long period of exposure. Some studies have also examined the risk of carcinogenicity and non-cancerous hazardous effects of silica in different exposure scenarios (Mannetje et al., 2002). The aim of this study was to evaluate the quantitative and semi-quantitative risk of exposure to silica, and the mortality and lung cancer risk due to exposure to crystalline silica among the stone carvers of Neyshabur city.

Materials and Methods

The present study was conducted in 2020 among the stone carvers of Neyshabur city. Initially, the list of all engraver workshops in Neyshabur were inquired from the Deputy of Health of Neyshabur city. The study involved 38 workshops with a total of 78 participants, who were required to complete an informed consent form prior to their participation. None of the stone carvers used any type of personal protective equipment (nose masks, gloves, eye goggles). All experimental protocols were approved in Neyshabur university of medical sciences by a licensing committee (ethics cod number: IR.NUMS.REC.1399.048)

The objectives of this study were explained to the employees and all carvers consented to enter the study. Participants were assured that their information will remain confidential.

All the work methods and related experiments have been done according to the instructions stated in the standards (Silica exposure assessment whit NIOSH7500 method, Semi-quantitative risk and Quantitative risk assessment whit Singapore Department of Occupational Health and US Environmental Protection Agency (EPA) methods, The relative risk of mortality from silicosis was calculated according to the Manettej model and The probability of mortality due to lung cancer was calculated using the linear regression model inferred from Rice.

Silica exposure assessment

In this study, in order to determine the exposure of stone carvers workers to repairable dust, sampling was conducted based on the NIOSH7500 method; and to determine the amount of crystalline silica in repairable dust the X-ray diffraction technique was used, which is the most accurate method for determining crystalline silica in air samples (Tibi et al., 2020).

Sampling of the respiratory area was performed using an individual sampling pump (model 224- pcxr3, SKC company, made in England), and a nylon cyclone, along with a PVC sampling filter with a diameter of 25 mm and a pore size of 0.8 microns. The sampling flow rate was 1.7 liters per minute and the duration was 5 hours. One sample was taken for each person during the 8-hour work shift. In order to remove moisture, the sampling filters were placed in a desiccator for 24 hours before and after sampling, and were weighed with a digital scale that had 0.000001 grams' accuracy. For every 5 samples, one control sample was taken, and the sampling steps taken were exactly the same, except that air was not pumped through them by the device. Then, the amount of exposure to total respiratory dust was calculated according to Equation 1.

$$\boldsymbol{C} = \frac{(\boldsymbol{W}2 - \boldsymbol{W}1) - (\boldsymbol{B}2 - \boldsymbol{B}1) \times 1000}{\mathbf{V}} \qquad \text{(Equation 1)}$$

C = Total respiratory dust density in mg/m^3

W1 and W2 = Filter weight before and after sampling in mg

B1 and B2 = weight of control filter before and after sampling in mg

V = Volume of sampled air in cubic meters (m^3)

Semi-quantitative risk

Semi-quantitative risk assessment was performed using the method suggested by the Singapore Department of Occupational Health (Kakooei et al., 2014). In this method, the degree of risk is first determined based on the toxic effects of the chemical composition (Appendix S1). Then, the Exposure Rate (ER) is calculated based on air monitoring results and exposure duration using Equation 2.

$$E = \frac{\mathrm{M} \times D \times F}{\mathrm{W}} \qquad \text{Equation 2}$$

E: Weekly exposure in mg/m^3 or ppm,

F: Number of times of exposure per week,

M: Exposure in ppm or mg/m^3,

W: Average working hours per week (40 hours),

D: Average time per exposure per hour

Eventually, the risk score is calculated using the chemical hazard (HR) value and exposure rate (ER) through equation 3. Then the risk rank is determined based on the risk ranking table in (Appendix S2,S3).

$$\text{Risk Level} = (HR \times ER)^{\frac{1}{2}}$$ Equation 3

Quantitative risk assessment

Quantitative risk assessment was performed according to the method suggested by the US Environmental Protection Agency (EPA) (EPA, 2011). In this method, the carcinogenic and non-carcinogenic adverse effects of a compound is determined. The carcinogenic risk of a chemical compound is calculated based on Equation 4 and the non-cancerous adverse health effects are calculated based on Equations 5 and 6.

$$LCR = \frac{\mathrm{C} \times \mathrm{BR} \times \mathrm{DS} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times SF$$ Equation 4

$$EC = \frac{C \times DS \times EF \times ED}{\mathrm{AT}}$$ Equation 5

$$\mathrm{HQ} = \frac{EC}{RfC}$$ Equation 6

LCR = incremental lifetime cancer risk
HQ = hazard quotient
C = exposure concentration in air (mg/m^3)
BR = breathing rate (m^3/hr)
DS = daily shift (hr/day)
EF = exposure frequency (day/ year)
ED = exposure duration (years)
BW = bodyweight (kg)
AT = averaging time for cancer effects (equals to the life expectancy in days)
SF = cancer slope factors (mg/kg.day), and
REL = chronic reference exposure level (mg/m^3).

Respiration rate depends on physical activity, and the respiratory rate is higher in men than women (Stifelman, 2007). Therefore, the EPA has categorized the respiration rate according to the level of activity in different genders, into light, medium and heavy classes. Activities such as office work, cleaning, minor repairs and carrying a cart weighing less than 15 kg are classified as light work (Kamaludin et al., 2020). Activities that are more energy consuming such as mountaineering, welding, repairing, long-distance walking, or pushing carts (over 15 kg load) are classified as moderate activities. Strenuous physical activity or engaging in two or more moderate activities at the same time, such as construction work, climbing while lifting heavy equipment, digging, running long distances, cycling, or chopping with an axe are classified as heavy activities .

Cancer Slope Factor (SF) is a 95% confidence interval for the risk of lifelong cancer due to exposure to a hazardous compound, provided by the IARC (Tibi et al., 2020). There is currently no specific SF for silica provided by the Integrated Risk Information System (IRIS) for health risk assessment. In animal and human studies, SF values have been estimated to be in the range of 1.85×10^{-5} to 6.8×10^{-7} (EPA, 2011). The values used for carcinogenic and non-carcinogenic risk assessment in this study are presented in Table 1.

According to the EPA standards, the acceptable risk level for environmental exposure to chemical compounds is defined as one per 1,000,000 and 1 in 1,000 in occupational contacts (EHHA, 2011). According to studies, LCR (lifetime cancer risk) more than 10^{-4} is classified as Definite Risk, 10^{-4} to 10^{-5} is classified as Probable Risk and between 10^{-5} to 10^{-6} is defined as Possible Risk (Mohammadyan et al., 2019).

$HQ > 1$ also indicates concern for non-carcinogenic hazardous effects and $HQ \leq 1$ indicates an acceptable risk level. The higher the numbers, the greater the risk, and the higher the risk, the greater the likelihood of adverse health effects from exposure to the chemical compound.

Evaluation of lung cancer mortality

The relative risk of mortality from silicosis was calculated according to the Manettej model considering cumulative exposure, which is calculated by multiplying exposure rate (in mg/m^3) and exposure duration (in years). In this model, cumulative silica exposure is classified into 9 exposure level categories. The first category includes exposures from 0 to 0.99 mg/m^3 and the last category includes exposures more than 28.1 mg/m^3 (Steenland et al., 2001).

In this study, in addition to the probability of mortality due to silicosis, the probability of mortality due to lung cancer was calculated using the linear regression model inferred from Rice et al and according to Equation 7 (Park et al., 2002).

$$A = 0.77 + 373.69 \times GM$$ Equation 7

Finally, data were entered into SPSS version 24. The geometrical means of exposure and their standard deviation were calculated. The one sample t-test was used to compare the measured exposure with crystalline silica and total dust thresholds. The level of significant was assumed to be 0.05.

Results

The number of participants in the present study was 79 workers (employed in 38 workshops). The mean age of the subjects was 38.30±10.63 with a mean work experience of 13.02±0.33 years. Sixty-one percent (61%) of the participants were non-smokers and 39% were smokers. Their demographic information is shown in Table 2.

The average exposure of stone carvers to total inhalable dust was 1.41±0.91 with a range of 0.13-4.33 mg/m^3 and the average exposure to crystalline silica was 0.50±0.33 with a range of 0.04-1.67 mg/m^3. The results of one sample t-test showed that the exposure of stone carvers to crystalline silica was significantly higher ($p < 0.0001$) than the threshold limits provided by ACGIH standards and the Iranian Occupational Health Technical Committee (0.025 mg/m^3) and the exposure of stone carvers to total respiratory dust was significantly higher ($p < 0.0001$) than the permissible level of ACGIH (1 mg/m^3) ($p < 0.0001$).

Also, the level of exposure of 58.2% (n = 46) of the stone carvers to total respiratory dust was above the allowable exposure limit; and all stone carvers (100%)

Table 1. The Values Used for Carcinogenic and Non-Carcinogenic Risk Assessment

Input parameter	Unit	Distribution values	Basis
Chemical concentration (C)	$mg.m^{-3}$	-	Data calculated
Breathing rate (BR)	$m^3.hr^{-1}$	for light activities (administrative workers) = 0.8	U.S. EPA (2011)
Daily shift, (DS)	hours/day	8	(working hours)
Exposure frequency (EF)	days/year	260	Questionnaire
Exposure duration (ED)	years	-	Questionnaire
Averaging time for cancer effects (equals to the life expectancy in years),(AT)	days	For carcinogenecity 70 years × 365 day/year = 25550 For non carcinogenecity 70years×365 day/years×24 hr=613200	U.S. EPA (2011)
Bodyweight, (BW)	kg	-	Data calculated
Cancer slope factors, (SF)	$mg.kg^{-1}.d^{-1}$	1.85×10^{-5}, 6.8×10^{-7}	Goldsmith et al. (1995)
Chronic reference exposure level, (RfC)	$mg.m^{-3}$	0.025	ACGIH (2018)

Table 2. Demographic Information of the Stone-Masons that Participated in This Study

	Minimum	Maximum	Mean	Std. Deviation
Age (years)	15.00	63.00	38.30	10.63
Job experience (years)	1.00	40.00	13.02	10.33
Weight (kg)	40.00	105.00	71.80	21.00
Height (cm)	90.00	185.00	167.77	15.01

had higher than threshold limits exposure to silica.

The semi-quantitative risk level of exposure to crystalline silica in stone carvers with a hazard rate of 4 was estimated using the table in (Appendix S1), based on the toxicity of the chemical composition. Also, the degree of exposure according to the hours of stone carvers' exposure per day and week to silica and according to the equations was estimated to be 5. (Appendix S2) Eventually, the semi-quantitative risk level was estimated to be very high (Table 3) (Appendix S3).

The carcinogenic risk of silica in stone carvers was estimated by considering the cancer slope factor in two different values: 1.85×10^{-5} and 6.8×10^{-7}. The results of carcinogenic and non-carcinogenic risk assessment are shown in Table 4. 97.5% of the participants were at an unacceptable level of non-carcinogenic risk for exposure to silica. According to Mannetje et al.'s model, 15.2% of stone carvers (12 people) were in the cumulative exposure level of 0-0.99 mg/m^3 per year with a predicted mortality rate of 1 person per thousand people, and 13.9% of people (11 people) were in the cumulative exposure level of 0.99 -1.97 and 4.33-7.12 milligrams per cubic meter per year with mortality rates of 3.4 and 13.7 people per thousand people, respectively (Table 5).

The total risk of death from lung cancer for masonry workers exposed to silica dust according to the Rice et al model, assuming the geometric mean value of 0.40 and according to Equation 6 was 150.24 people per thousand workers exposed to silica.

Discussion

In this study, the average occupational exposure to total inhalable dust was above the defined standard limit (1 mg/

Table 3. Semi-Quantitative Risk Assessment in the Stone Masons under Study

Risk Level	Risk	exposure rate (ER)	E/OEL*	Weekly exposure	Hazard Rate (HR)	Occupation
Very high	4.47	5	14.8	0.37	4	Stone masons

* E, Weekly exposure in mg/m^3, OEL, Occupational exposure limit

Table 4. Non-Carcinogenicity Risk Assessment Results and LRC in the Stonecutters

	Cancer Slope factor	Minimum LCR	Maximum LCR	Mean LCR	Risk Level N (%)	
					acceptable	not acceptable
Incremental Lifetime Cancer Risk (LCR*)	1.85×10^{-5}	3.7×10^{-7}	5.27×10^{-5}	7.40×10^{-6}	12 (15.2)	67 (84.8)
	6.8×10^{-7}	1.36×10^{-8}	1.93×10^{-6}	3.12×10^{-7}	74 (93.7)	5 (6.3)
Hazard Quotient (HQ)**	-	0.76	142.6	23.38	2 (2.5)	77 (97.5)

*LCR (lifetime cancer risk) does not have a unit. LCR>10-4 is classified as Definite Risk, 10-4 to 10-5 is classified as Probable Risk and between 10-5 to 10-6 is defined as Possible Risk. ** HQ>1 indicates concern for non-carcinogenic hazardous effects, but HQ≤ 1 indicates an acceptable risk level.

Table 5. Relative Risk of Mortality in Stone Masons due to Silicosis Based on the Mannetej Model

Cumulative exposure (mg/m^3)	Mortality rate for silicosis exposure (per 1000 people)	Number of exposed stone masons (%)
0-0.99	1	12 (15.2)
>0.99-1.97	3.4	11 (13.9)
>1.97-2.87	6.2	8 (10.1)
>2.87-4.33	9.4	10 (12.7)
>4.33-7.12	13.7	11 (13.9)
>7.12-9.58	22.6	7 (8.9)
>9.58-13.21	24	7 (8.9)
>13.21-15.89	40.2	4 (5.1)
>15.89-28.1	52.1	6 (7.6)
>28.1	63.6	3 (3.8)

m^3) and the exposure level of more than half were higher than the standard limit (1 mg/m^3). The average exposure to crystalline silica was 20 times higher than the occupational exposure limits provided by the ACGIH organization and the Iranian Occupational Health Technical Committee, and all stone carvers were exposed to silica that was higher than the occupational exposure limit of 0.025 mg/m^3 (Park et al., 2002).

Golbabai et al. investigated the level of exposure to crystalline silica in 62 cement factory workers in 2012, and stated that the range of exposure to crystalline silica in all production units was 0.104-0.011 mg/m^3 (Park et al., 2002). In a cross-sectional study in 2014, Tavakol et al., (2016) evaluated occupational exposure to silica in 85 construction workers. The average exposure of workers to total respirable dust was 8.9 ± 0.35 mg/m^3 and to respirable crystalline silica dust was 0.13± 0.019 mg/m^3 (Golbabaei et al., 2012). In the study conducted by Askarpour et al., (2015) in a tile and ceramic production complex, the average occupational exposure to general dust and crystalline silica was estimated to be 7.38 ± 5.15 mg/m^3, and 0.29 ± 0.19 mg/m^3 respectively (Golbabaei et al., 2012). Moghadam et al., (2020) estimated the average exposure to crystalline silica in 70 workers working in the concrete industry to be 0.025 ± 0.008 mg/m^3. In the study of Mohammadi et al., (2017) the average exposure to silica in 60 male workers in the silver industry was estimated to be 0.25 ± 0.13 mg/m^3. The results of semi-quantitative risk assessment in the stone carvers of this study showed that the workers were at a very high risk. The results of Mohammadi et al., (2017)'s study, conducted in a cement factory using the semi-quantitative risk assessment method of Singapore, showed that the workers were at medium risk, which is a lower risk level compared to the present study. The most rational explanation for the lower risk level in Mohammadi et al., (2017) 's study is that in their study, the risk assessment of exposure to cement dust was considered, which is a less dangerous substance than silica, and in the calculations related to risk assessment, a lower risk level is allocated to cement and consequently the risk level is estimated to be lower. In this study, the average risk of lung cancer in carvers, considering the slope factor of cancer at 1.85×10^{-5} was equal to 7.40×10^{-6}, and in the range of 3.7×10^{-7} to 5.27×10^{-5}; and considering the slope factor of cancer at 6.8×10^{-7} was 3.12×10^{-7} in a range of 1.36×10^{-8} to 1.93×10^{-6} and in both cases, a number of workers were at values higher than 10^{-6} which means unacceptable risk level. Shojaee Barjoee et al., (2020) evaluated the carcinogenic and non-carcinogenic risk of exposure to crystalline silica in a Chinese industrial unit. The average occupational exposure to crystalline silica was 0.57 ± 0.1 mg/m^3 and in all occupational groups the risk of carcinogenesis was less than 10-6 and was within acceptable limits. Also, in Mohammadi Kaji's study, the levels of cancerous and non-cancerous risks of 15 occupational groups exposed to crystalline silica dust in the welding electrode production process with two cancer slope factors of 1.85 and 6.8 were investigated and the risk level of all people in all occupational groups was lower than 10-6 which means at acceptable level (Mohammadi Kaji, 2014).In this study, the average non-carcinogenic risk assessment of exposure to silica was 23.38 and 97.5% of people were at unacceptable risk level, i.e. higher than one. In Shojaee et al., 2019 study, the non-carcinogenic risk in a chinaware manufacturing industry, in stone crusher, slurry, filter press and dryer occupational groups was higher than one and in the unacceptable range. In the current study, the biggest group of stone carvers (15.2 percent) were at the cumulative exposure level of 0-0.99 mg/m^3 per year with a mortality rate of 1 per 1000, for exposure to silicosis. Also, the risk of death due to lung cancer using Rice et al.'s model for masonry workers exposed to silica dust was estimated to be 150.24 per thousand workers exposed to silica. In Nourmohammadi et al., (2018) 's study in the tile and ceramic industry, similar to the present study, the biggest group of workers (24.5%) were at the cumulative exposure level of 0-0.99 mg/m^3 per year with a mortality rate of 1 per 1000 people and the risk of death from lung cancer, was in the range of 41 to 124 per thousand people. In the study conducted by Tavakol et al.,2016 among construction workers in 2015, the biggest group of workers (69.41%) were at the cumulative exposure level of 0-0.99 mg/m^3 per year, and the risk of death due to lung cancer was in the range of 21-49 per thousand. In Mohammadi et al.'s study, the risk of death due to silicosis for the biggest group of insulator industry workers (25%) was at the cumulative exposure level of 0-0.99 mg/m^3 per year and the risk of death due to lung cancer ranged from 7 to 94 per thousand workers exposed to silica (Mohammadi et al., 2017). In Zarei et al., (2017)'s study conducted in, among core making workers of a foundry factory, most of the workers (41.8%) were exposed to a cumulative exposure level of >28.1 mg/m^3 per year, and the estimated mortality rate was 63.6 per thousand, and the increased risk of death due to lung cancer was estimated to be 65 per thousand with a range of 19 to 897. Moghadam et al., 2017 estimated the risk of death due to lung cancer in concrete workers exposed to silica between 7 to 94 per thousand. In some studies, risk assessment has been carried out in both semi-quantitative and quantitative ways, and each method has its strengths and weaknesses. Also, the different values of the permissible occupational exposure thresholds provided by different organizations cause different conclusions in studies, because one of the main parameters used in the calculations related to quantitative and semi-quantitative risk assessment is the standard value. In 2010, the American Conference of Governmental Industrial Hygienists (ACGIH) set the occupational exposure threshold to respirable crystalline silica as 0.025 mg/m^3, the Occupational Safety and Health Administration (OSHA) set the threshold at 0.01 mg/m^3 and the National Institute for Occupational Safety and Health (NIOSH) suggested 0.05 mg/m^3 as the threshold (ACGIH 2018, OSHA 2010, NIOSH 2003). Currently, the safety limit of occupational exposure to respirable crystalline silica in Iran is 0.025 mg/m^3. The other reason for different study results is that in some studies, the geometric mean of exposure to silica and in some the arithmetic averages have been presented. Here, the results of studies that were similar in terms of at least the analysis method and risk assessment method, were compared with the results of this study.

Among the limitations of this research were the time restrains for research implementation, equipment error, and the high cost of analyzing dust samples to determine the amount of crystalline silica. It is suggested that future studies include more variables including different seasons of the year, because the amount of wind speed, temperature, air pressure and general and local ventilation are also effective on the amount of dust spread and exposure. Another limitation of the study, that sample size for the study was small and that results of their study could be the nidus on which further larger studies would be based.

In conclusion, the average exposure to crystalline silica in carvers was higher than the permissible limit. Some workers were at risk of acquiring cancer and the majority of them were at an unacceptable non-cancerous risk. Therefore, it is necessary to implement engineering control measures and appropriate respiratory protection programs. One of the most important ways of control is raising the awareness of workers and monitoring their work. Also, optimization of general and local ventilation systems, avoiding the spilling of raw materials, using water spray to wash the floor and surfaces, avoiding cleaning equipment with compressed air and instead using water and industrial vacuum cleaners, implementation of respiratory protection programs, use of work rotation systems, observance of workplace discipline, training and annual medical examinations for timely diagnosis and treatment can decrease workers' health risk.

Author Contribution Statement

SR: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. NK, ME, MNH,AG, SY: Investigation, Methodology, Writing – review and editing. MN: Methodology, Writing – review & editing, Supervision. All authors read and approved the final manuscript

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Data availability

The datasets generated and analyzed during the current study available from the corresponding author on reasonable request.

Conflicts of interest

The authors of this article declare that they have no conflict of interests.

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