International Journal of Biology Sciences

ISSN Print: 2664-9926
ISSN Online: 2664-9934
NAAS Rating (2025): 4.82
IJBS 2025; 7(9): 46-51
www.biologyjournal.net
Received: 19-06-2025
Accepted: 21-07-2025

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Respiratory distress and lung function among stone crushing unit workers

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DOI: https://www.doi.org/10.33545/26649926.2025.v7.i9a.478

Abstract
Stone-crushing although an important industrial sector in India has continuously been associated with health and safety related issues. The exposures from the dust emanated by various mechanical process such as drilling, dressing and loading, can trigger health issues ranging from minor symptoms to severe diseases and even cancers if worsened. In this view, the present study aimed at assessment of respiratory distress and lung function profile of the workers (n=46; aged 44.47±1.18y). The interview method was used to collect the information from the workers regarding their demographic, lifestyle and health related concerns. The lung function was assessed using spirometer using standard methodology. The results of the study revealed that the majority of workers had complaints of cough, breathlessness, dust particles in sputum and wheezing. Blocked and stuffed nose, loss -of- appetite and tiredness and joint pains were the other health complaints reported by the workers. The lung function stratified according to activities revealed a significant decline in lung function in those employed in drilling followed by the dressers and loaders. The workers were also categorized as having moderate (n=24), severe (n=14) and very severe COPD according to the lung function parameters as per the GOLD guidelines. Body Mass Index, years of smoking, Brinkmann index, duration of work and work schedule emerged as significant predictors of decline in lung function the present study is a risk assessment in regard to safeguarding the health of workers employed in such units. The results of this study can help in implementation of surveillance and establishing precautionary approaches for making such workplaces to be better and safer in terms of health of those employed.

Keywords: Lung function, stone crushing, respiratory distress, COPD

Introduction
The construction industry caters to the need of raw material for construction and infrastructural development. In India the construction industry has been on a high-growth trajectory with about 1.5 times the country's overall development and mainly employs unskilled, migrant, socially-backward and uneducated labourers who are predominantly, migrant workers are belonging to the northern states such as Odisha, Bihar, West Bengal, Chattisgarh (Krishnakumar and Indumathi, 2015) [19].

Occupational activities in stone crushing industry involve crushing, drilling and loading generating several environmental contaminants which are health-hazardous and can be inhaled and/ or absorbed dermally. In India and elsewhere, the ambient concentrations and exposure levels of dust at stone-crushing sites exceed the National Standards as reported from Chennai (Sivacoumar *et al*., 2006) [32] and by the Occupational Safety and Health Administration permissible exposure limit (OSHA PEL) in Iran (Bahrami *et al*., 2008) [1]. Silicon dioxide/ free silica is a major component of dust (Sobti and Bhardwaj, 1991; Chattopadhyay *et al*., 2006; Gottesfeld *et al*., 2008) [33, 3, 8]. Other metal iron, zinc, cadmium, nickel, lead, chromium, barium, beryllium, and aluminium as reported from stone crushers in Abia State, Nigeria (Ugbogu *et al*., 2009) [35], oxides of aluminum (Al_2O_3), iron oxide (Fe_2O_3), Calcium (CaO), Magnesium (MgO), Potassium (K_2O), Sodium (Na_2O), and Titanium (TiO_2) in stone crushers near Chandigarh (Sobti and Bhardwaj, 1991) [33] and also in Turkey. Particulate matter (PM) exposure is associated with risk for CVD (Brook *et al*., 2010; Tseng *et al*., 2015; Du *et al*., 2016) [2, 34, 5], respiratory distress (Neuberger *et al*., 2004; Kyung and Jeong, 2020) [27, 22], Parkinson disease (Palacios).

With scarce use of the protective measures, the workers at stone crushing units and residents near stone crushing units, the general environmental and occupational exposure coexists potentiating their vulnerability to ill-health from inhalation, dermal absorption ingestion or sedimentation of the dust particles.

A few earlier studies from different units within India (Sobti and Bhardwaj, 1991; Kaur and Gandhi, 2011 a, b; Sivacoumar *et al*., 2001) [33, 16, 32] and abroad documented the potential environmental and health impacts because of exposure from this sector, the baseline exposure-situation from Punjab is rather sparse. Therefore, in the present study *in situ* pulmonary function test assessment to identify those with respiratory insufficiency and at risk for Chronic Obstructive Pulmonary Disease (COPD) was carried out in those engaged in different work activities at the stone-crushing units in the Gurdaspur and Pathankot districts of Punjab.

Materials and Methods

Study Design: The present study is a cross-sectional study conducted after approval from the Institutional Ethics Committee. The study group comprised unrelated individuals surveyed after written, informed voluntary consent from five stone-crushing units in Gurdaspur (32° 03'N, 75°27'E) and Pathankot (32° 17' N, 75° 42' E) districts of Punjab.

Study Participants: The proprietors/owners of the units were requested for permission to contact regularly-employed workers at the stone crushing units. A face-to-face interview method was used to collect demographic, work-related, health and reproductive history of the study participants on a specifically designed questionnaire.

The Exclusion criteria were those undergoing any treatment(s) or medication(s) and those below 18 years of age. For inclusion in the study, criteria comprised unrelated (males) adults working at the stone- crushing units for more than five years.

Nutritional Status Assessment: Using a steel tape height (cm) and a weighing machine, weight (kg) were recorded as recommended by Weiner and Lourie (1981) [36]. To assess the nutritional status, Body Mass Index (BMI in kg/m^2) was calculated by dividing the weight (kg) by square of height (m^2).

Pulmonary Function Assessment- The pulmonary function testing carried by using a spirometer (Spiro Excel, Medicaid Systems, India) and a record for each worker was maintained for forced expiratory volume per second (FEV_1; l), Forced Vital capacity (FVC; l), Forced Expiratory Ratio (FEV_1 /FVC), predicted values of FEV1 and FVC from the software and of body surface area (BSA, m^2). The workers were then categorized into different COPD categories as per the GOLD (Global Initiative for Chronic Obstructive Lung Disease) guidelines (2010).

Statistical analysis*:* Demographic variables, occupational information and health effects are given as ranges (min-max), numbers and percentages. The continuous study characteristics and the lung function parameters are presented as mean ±S.E.M. One way Analysis of Variance (ANOVA) was performed for multiple comparisons of the lung function parameters between work activity types and COPD categories. Pearson correlation analysis checked for any association between lung function and confounding variables. To identify the predictors of decline in lung function multiple linear regression analysis was performed. All the statistical analysis was done using the SPSS (version 16). The p value ≤0.05 was considered for significance.

Results

Male workers (n=46; male) at stone-crushing units for 7-18y (11.19± 0.40y) and aged 32-60y (44.47±1.18y) comprised the study participants (Table 1). On the basis of education level, occupation and monthly income (Kumar), workers had low middle socio-economic status. BMI (16.81-25.72kg/m^2) revealed 21.73%underweight and 4.34% obese and the BSA was 1.60± 0.01 m^2 (range 1.48-1.81m^2). Brinkmann index (multiplying number of *bidis* (Indian rolled cigarettes) smoked with years of smoking) ranged from 120-480 (270.54±14.44).The main occupational activities of the workers were stone-drilling (32.60%), -dressing (34.78%) and -loading (32.60%) with a daily work schedule of 8-12h (10.00±0.29h). Occasional alcohol drinking was prevalent among 54.34% while all smoked and chewed tobacco.

The workers mostly complained of respiratory distress (Table 2) from workplace exposure. Cough, breathlessness, dust particles in sputum and wheezing were self-reported by 39.13%; 26.08% had the first three complaints and of blocked and stuffed nose, whereas in addition to these, 10.56% also had problem of wheezing. The other major complaints included loss -of- appetite and tiredness (28.26%) and joint pains (13.04%).

Lung-function (Table 3) was lowest in the drillers followed by that in dressers and loaders. The FEV_1 (p=0.016) and the per cent FEV $_1$ (p=0.008) were significantly decreased (~ 1.37 folds) in drillers compared to the loaders (1.35 fold) fold significantly decreased FEV_1 (p=0.018) and % predicted FEV_1(0.010) was observed in dressers in comparison to the loaders (Table 4). As a function of COPD categories (Table 4) the FEV_1 and the FEV_1/FVC values were decreased in very severe cases than those severe and moderate COPD cases. The FVC values were almost similar in severe and very severe categories but were decreased from those in moderate cases. The % predicted values of FEV_1, FVC as well as FEV_1/FVC were all lower in very severe cases followed by severe and moderate cases. The FEV_1 was decreased significantly 1.54 times in severe COPD cases (p=0.000) and 2.41 times in very severe COPD cases (p=0.000) in comparison to the moderate COPD cases. FEV_1 was also significantly (p=0.004) 1.56 fold decreased in very severe COPD cases compared to the severe COPD cases. The FVC values were significantly decreased 1.25 fold (p=0.010) in severe COPD cases when compared to the moderate cases. The per cent predicted values of FEV_1/FVC decreased significantly in very severe COPD cases in comparison to severe (p=0.031) and moderate COPD cases (p=0.001).

The correlation analysis (Table 5) revealed a negatively significant association of age (p=0.000), COPD categories (p=0.000), smoking per day (p=0.049), years of smoking (p=0.001) and brinkmann index (p=0.001) with FEV_1, though the work type at the workplace was positively (p=0.007) associated to FEV_1. BMI (p=0.000), BSA (p=0.018) and COPD categories (p=0.021) were negatively correlated to FVC. The FEV_1/FVC was observed to be negatively associated to age (p=0.000), COPD categories

(p=0.000), years of smoking (p=0.002) and brinkmann index (p=0.003) though was positively correlated to BMI and BSA. To assess for any predictors of decline in lung function, multiple linear regression analysis (Table5) was done. BMI (p=0.000), BSA (p=0.004), COPD (p=0.000), work activities at workplace (p=0.039) and alcohol were observed to be significant predictors of decline in FEV_1. The predictors of decline in FVC values were BMI (p=0.000), COPD (p=0.011), work duration (p=0.036). The FEV_1/FVC ratio was significantly influenced by BSA (p=0.001), COPD (p=0.002), years of smoking (p=0.053), brinkmann index (p=0.042), duration of work (p=0.024) and work schedule (p=0.006).

Table 1: Demographic Characteristics of the Workers at the Stone-crushing Units

Characteristics			Workers	
			Range/N (%)	**mean± S.E.M.**
Age (y)			32-60	**44.47±1.18**
Lifestyle Pattern	Diet - Veg/ Non-veg (occasional)		13 (28.26)/33 (71.73)	-
	Smoking habit -Yes/ No		46.00(100.00)	-
	†Brinkman Index		120-480	270.54±14.44
	<200		16(34.78)	174.06±6.56
	<300		15(32.60)	250.73±7.01
	<400		09(19.56)	364.22±10.28
	<500		06(13.04)	43.68±11.46
	Tobacco +lime chewing(continuous)-Yes/No		46.00(100.00)	-
	Alcohol drinking (750-900ml/week)- Yes/ None		25(54.34)/21(45.65)	-
	[a]Socio-economic Status	Lower middle	46.00(100.00)	-
Nutritional Assessment	[b]Body Mass Index(kg/m^2)		16.81-25.72	20.17±0.33
	<18.00(underweight)		10(21.73)	-
	18.00-22.90(normal)		31(67.39)	-
	23.00-24.90(overweight)		03(6.52)	-
	>25.00(obese)		02(4.34)	-
	Body Surface Area (m$^{2)}$		1.48-1.81	1.60±0.013
Occupational exposure	Duration of Work (y)		7-18	11.19±0.40
	Work Schedule per day (h)		8-12	10.00±0.29
	Work Activities	Drilling	15(32.60)	-
		Dressing	16(34.78)	-
		Loading	15(32.60)	-

† Kojima *et al*., (2005); [a]Kumar *et al*. (2012); [b] WHO (2004)., Misra *et al*. (2009)

Table 2: Health Effects Reported by the Workers at the Stone-crushing Units

Ill-health Indicators		N (%)
Respiratory Distress	Cough, Breathlessness, Dust Particles in Sputum, Blocked and Stuffed Nose	12
	Cough, Breathlessness, Dust Particles in Sputum, Wheezing, Blocked and Stuffed Nose	05
	Cough, Breathlessness, Dust Particles in Sputum, Wheezing	18
	Cough, Breathlessness, Dust Particles in Sputum	08
	Cough, Breathlessness, Blocked and Stuffed Nose	03
	Total	46
Other Ill-health Symptoms	loss of appetite, tiredness, watering of eyes, skin irritation, joint pain	03
	watering of eyes, skin irritation, joint pain	03
	loss of appetite, tiredness, joint pain	06
	loss of appetite, tiredness, watering of eyes, joint pain	01
	loss of appetite, tiredness, watering of eyes, skin irritation	01
	tiredness, watering of eyes, joint pain	03
	loss of appetite, tiredness	13
	watering of eyes, joint pain	04
	tiredness, joint pain	05
	tiredness, watering of eyes	01
	watering of eyes	05
	joint pain	01
	Total	46

Table 3: Lung Function Parameters as a function of Work Activities at the Stone-crushing Units

Pulmonary Function Parameters	Work Categories			Total
	Drilling (N=15)	**Dressing (N=16)**	**Loading (N=15)**	
FEV_1	1.51±0.14[a1]	1.53±0.11[a]	2.08**±0.15[b]	1.70±0.08
FVC	2.85±0.19	2.93±0.18	3.25±0.14	3.01±0.10
FEV_1/ FVC	0.57±0.04	0.56±0.03	0.60±0.03	0.58±0.02
% $FEV_{1\ predicted}$	45.12±1.08[a1]	45.97±3.03[a]	61.50**±3.68[b]	50.76±2.32
%$FVC_{predicted}$	71.08±4.96	74.02±5.08	80.46±3.11	75.16±2.61
%FEV_1/ $FVC_{predicted}$	0.72±0.05	0.71±0.04	0.76±0.04	0.73±0.02

Values with different letters are significantly different;
FEV_1 : a1 *vs* b, p=0.016; a *vs* b, p=0.018
% $FEV_{1\ predicted}$: a1 *vs* b, p=0.008; a *vs* b, p=0.010

Table 4: Lung Function Parameters as a function of COPD Categories in the Workers at the Stone-crushing Units

Pulmonary Function Parameters	COPD Categories			Total
	Moderate(N=24)	Severe(N=14)	Very Severe(N=08)	
FEV_1	2.15***±0.08[a]	1.39**±0.05[b/c]	0.89±0.14[b/d]	1.70±0.08
FVC	3.29**±0.10[a]	2.63±0.16[b]	2.83±0.33	3.01±0.10
FEV_1/ FVC	0.63±0.01	0.57±0.03	0.42±0.08	0.58±0.02
% $FEV_{1\ predicted}$	62.66±2.12	43.28±1.14	28.12±1.52	50.76±2.32
$\%FVC_{predicted}$	79.98±2.37	68.24±5.26	72.82±9.14	75.16±2.61
$\%FEV_1/FVC_{predicted}$	0.79***±0.01[a]	0.73*±0.04[a1]	0.54±0.10[b]	0.73±0.02

Values with different letters are significantly different;
FEV_1: a *vs* b, p=0.000; c vs d, p=0.004
FVC**:** a *vs* b, p=0.010
$\%FEV_1/FVC_{predicted}$: a *vs* b, p=0.001; a1 *vs* b, p=0.031

Table 5: Predictors of Lung Function Parameters

Dependent Variables	Independent Variables	Pearson Correlation		Multiple linear regression		
		r	P value	β	t	P value
FEV_1	Age	-0.596	0.000	-0.158(-0.30-0.007)	-1.294	0.205
	BMI	-0.097	0.520	-0.414(-0.158- -0.059)	-1.483	0.000
	BSA	0.082	0.589	0.277(0.617-2.994)	3.090	0.004
	COPD	-0.842	0.000	-0.736(-0.702- -0.443)	-8.997	0.000
	Work type	0.395	0.007	0.151(0.006-0.215)	2.145	0.039
	Diet	-0.150	0.320	0.021(-0.172-0.227)	0.280	0.781
	Alcohol	0.001	0.995	0.105(-0.044-0.292)	1.499	0.014
	Smoking years	-0.479	0.001	0.587(-0.018-0.152)	1.608	0.117
	Smoking per day	-0.292	0.049	0.488(-0.057-0.288)	1.367	0.181
	Brinkmann Index	-0.476	0.001	-0.987(-0.013-0.001)	-1.741	0.117
	Duration of Work	-0.318	0.031	0.029(-0.034-0.047)	0.325	0.747
	Work Schedule	0.016	0.915	0.058(-0.026-0.060)	0.808	0.425
FVC	Age	-0.140	0.352	0.162(-0.022-0.050)	0.802	0.428
	BMI	-0.584	0.000	-0.763 (-0.330- -0.139)	-4.999	0.000
	BSA	-0.346	0.018	0.070 (-1.763-2.834)	0.474	0.639
	COPD	-0.340	0.021	-0.363 (-0.581- -0.080)	-2.685	0.011
	Work type	0.231	0.123	0.167 (-0.060-0.345)	1.430	0.162
	Diet	-0.013	0.933	-0.096 (-0.532-0.238)	-0.777	0.442
	Alcohol	0.013	0.932	0.110 (-0.173-0.478)	0.955	0.347
	Smoking years	-0.018	0.906	-0.483 (-0.228-0.099)	-0.799	0.430
	Smoking perday	-0.041	0.788	-0.485 (-0.468-0.199)	-0.821	0.417
	Brinkmann Index	-0.007	0.961	0.885 (-0.007-0.020)	0.944	0.352
	Duration of Work	-0.169	0.262	-0.325 (-0.161- -0.006)	-2.183	0.036
	Work Schedule	0.043	0.776	0.190 (-0.017-0.148)	1.607	0.118
FEV_1/FVC	Age	-0.511	0.000	-0.291(-0.012-0.002)	-1.521	0.138
	BMI	0.385	0.008	0.058(-0.015-0.023)	0.399	0.693
	BSA	0.545	0.000	0.505(0.353-1.271)	3.599	0.001
	COPD	-0.504	0.000	-0.422(-0.131- -0.031)	-3.298	0.002
	Work type	0.089	0.558	-0.103(-0.059-0.022)	-0.936	0.356
	Diet	-0.207	0.167	0.087(-0.049-0.105)	0.744	0.105
	Alcohol	-0.004	0.979	0.017(-0.060-0.070)	0.152	0.880
	Smoking years	-0.447	0.002	1.145(0.000-0.065)	2.005	0.053
	Smoking perday	-0.221	0.139	1.029(-0.006-0.127)	1.843	0.074
	Brinkmann Index	-0.435	0.003	-1.873(-0.006-0.000)	-2.112	0.042
	Duration of Work	-0.209	0.163	0.158(-0.007-0.024)	1.120	0.024
	Work Schedule	-0.084	0.579	-0.146(-0.027-0.006)	-1.307	0.006

P values in bold are significant ($p \leq 0.05$)

Discussion

As stated in literature, the present study also showed that stone- crushing is associated with a high frequency of respiratory symptoms and other ill-health effects. The lung function of workers helped to characterize the workers as having chronic obstructive pulmonary disease probably from aggravation from exposure to irritants at the workplace. Dust at stone-crushing was reported to have components of heavy metals *viz*. lead, chromium, cadmium, selenium, nickel, iron and titanium with silica as a major component (Sobti and Bhardwaj, 1991; Golbabaei *et al*., 2004; Gottesfeld *et al*., 2008;Ugbogu *et al*., 2009) [33, 6, 8, 35]. There is also ample evidence that occupational exposures from vapors, gas, dust, and fumes are risk factors for COPD (Omland *et al*., 2014) [29]. Silica dust induced pathological changes which could cause development of COPD (Hnizdo and Vallyathan, 2003) [11] probably from chronic inflammation, bronchitis and emphysema as reported in response to inhalant oxidants generated by smoking and other environmental exposures (Olivieri and Scoditti, 2005; Sangani and Ghio, 2011) [30, 31]. Cell injury/ cytotoxicity in lung tissues can obstruct air flow **(**Miller and Zachary, 2017)

[23]. The multi-causal nature of COPD results from the interaction of various risk factors at workplace or from lifestyles can pre-empt generation of reactive oxygen/ nitrogen species, secretion of proinflammatory factors, cytokines, chemokines, elastase, (Li *et al*., 1996; Li *et al*., 1997) and fibrogenic factors. Besides smoking, air pollution, infections, socioeconomic status or host factors (genes, airway hyper-responsiveness, or lung growth have also been independently related to an increased risk for COPD.

All the workers had respiratory distress and declined lung function with characteristics of moderate, severe or very severe COPD. Despite this, the workers did not consult any physicians and were not on any treatments. Determinants of declined lung function were Workplace exposure, different activities of crushing, smoking and BMI. In literature also, occupational consequences have been reported to include significant decrease in the mean values and percent predicted values of lung function in construction workers, with increased impairment from duration of dust-exposure at construction site (Jhoncy *et al*., 2011) [15]. Quarry workers in Ebonyi State, Nigeria reported respiratory problems of chest pain, occasional cough, shortness of breath, wheezing and decline in lung function with a significant inverse correlation of FEV_1 with duration of exposure (Nwibo *et al*., 2012) [28]. Significant reduction in mean values of FVC, FEV_1, FVC/FEV_1 per cent, PEF, and FEF25-75 per cent was reported in quarry workers in Andhra Pradesh and reduction of pulmonary function showed positive correlation with duration of work (Kumar *et al*., 2014) [20]. Other health issues in workers engaged at a stone crusher in Bhopal were musculoskeletal problems, generalized weakness and breathing difficulties with respiratory problems higher in those >5y of occupational exposure (Narkhede *et al*., 2012).Both quarry (Ugbogu *et al*., 2009; Golbabaei *et al*., 2004) [35, 6] and stone-crusher (Sivacoumar *et al*., 2006) [32] workers have self-reported cough, shortness of breath, eye-irritation and watering, blocked/stuffed nose, dry/sore throat, tiredness and joint/muscle pains as also reported by the present study participants.

Besides employees, the environmental and occupational exposures can compromise the health conditions of those living nearby such units. Inhalation in airways can induce an inflammatory reaction, fibrosis which can initiate defective oxygen diffusion and lung function impairement (Jhoncy *et al*., 2011) [15]. Decreased pulmonary function has the potential to progress to lung damage and lung disease. Inhalation of dust particles for long periods reportedly caused silicosis (Sivacoumar *et al*., 2006) [32], pneumoconiosis (Green *et al*., 2008) and chronic obstructive pulmonary disease (Iftikhar *et al*., 2009) [12]. Inhalable particulate matter (PM) can impair lung function and cause respiratory damage, which in severe cases can lead to lung cancer (Sivacoumar *et al*., 2006) [32]. The processes at stone-crushing units release dust rich in crystalline silica; its exposure is linked to chronic lung disease, tuberculosis, chronic renal disease and also the autoimmune diseases of rheumatoid arthritis (Gottesfeld *et al*., 2008) [8].

Therefore, the results of the present study support evidence in literature linking exposure to occupational hazards with adverse effects. These may initiate as asymptomatic physiological and biochemical changes and progress onto severe lung disease (Ilyas *et al*., 2010; Nwibo *et al*., 2012) [28] and mortality (Nwibo *et al*., 2012) [28]. Impaired pulmonary function and respiratory distress have been observed in the workers at stone-crushing units in the present study. All of these have symptomatology and decreased ling-functions characteristics of various stages of chronic obstructive pulmonary disease. A dire need to sensitize the employer/employee duo has been observed though during the course of the study, appropriate counsel has been given for periodic general health and lung-function monitoring. The absence of precautionary measures in setting-up of stone-crushing units as per recommendations and non-use of adequate protective gear are other notables which can have health consequences on workers.

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