

Quantification of Reduction in Forced Vital Capacity of Sand Stone Quarry Workers

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Abstract: This study assessed the reduction in forced vital capacity of lungs of sand stone quarry workers exposed to high respirable suspended particulate concentration. The sand stone quarry workers are engaged in different type of activities like drilling, loading and dressing. These different working places have different concentration of RSPM and these workers are exposed to different concentration of RSPM. It is found that exposure duration and exposure concentrations are main factors responsible to damage respiratory tract of worker. It is also revealed from the study that most of the workers are suffering from silicosis if the exposure duration is more than 15 years.

Keywords: Forced Vital Capacity (FVC), Respirable Suspended Particulate Matter (RSPM), silicosis, respiratory tract

List of Notations and Abbreviations

Notations / Abbreviations	Description	Notations / Abbreviations	Description
Y	Dependent variable	$F_{k, n-k-1, \alpha}$	Critical value of F for given set of degree of freedom and significance
V_1 and V_2	Degree of freedom	X_1 and X_2	Independent variables
$t_{v_1, \alpha/2}$	$\alpha/2$ % critical value of student's "t" statistics for $(n_1 - 1)$ degrees of freedom	$\beta_0, \beta_1,$ and β_2	Unknown parameters, or constants of regression
$t_{v_2, \alpha/2}$	$\alpha/2$ % critical value of student's "t" statistics for $(n_2 - 1)$ degrees of freedom	k	Number of independent variable
t	Calculated value of t-statistic	N or n	Random sample size
$t_{n-k-1; \alpha/2}$	Critical value of "t" for given set of degree of freedom and significance	R	coefficient of correlation
F	F-distribution parameter (calculated)	H_0	null hypothesis
α	Level of significance	H_1 & H_2	Alternate hypothesis
		d.f.	Degree of freedom
		R^2	Coefficient of determination
		H	Height
		A	Age

Introduction

It is more than likely that man has suffered from occupational diseases over a span of time from hunting to agriculture as a means of feeding himself. After the industrial revolution the occupational diseases have been increased and adequate medical and scientific expertise allowed rapid progress to be made towards logical and scientific understanding. The mining industry is a great cause of occupational diseases. The consequence of an inhaled particle depends on its inherent toxicity, its ability to penetrate the site at which it can exert its effects and the amount retained in the lungs [2]. The sand stone quarrying has been established as the largest industry of Jodhpur (India). More than hundred thousand workers are employed for quarrying and its related activities [3]. Jodhpur sand stone rests uncomfortably over a highly rugged basement of Malani Rhyolite (745 ± 10 million years) and has been assigned Cambrian Age [5]. Structurally Jodhpur rocks are undeformed, lithofacies and are almost horizontal which helps towards easy quarrying [6]. Stones are primarily quarried by manual methods but now heavy machines are also used. In the process of stone quarrying particulate matter is generated and the workers involved in the different activities are exposed to the polluted environment during working hours (8hrs/day) and this polluted environment creates health problems to the workers. The working capacity of workers starts decreasing with the increase of working duration in quarries. This decrease in working capacity is because of the damages in the respiratory tract due to deposition of RSPM. Forced vital capacity (FVC) of lung is the actual volume of air expelled by a forced maximal expiration from a position of full inspiration. FVC_p is the predicted FVC of lung if person is not exposed to polluted environment that means FVC_p is normal value of FVC for a person. If FVC is less than FVC_p it indicates damage in the respiratory tract. If FVC is reduced it indicates both obstructive and restrictive respiratory disease. Therefore FVC was taken as the parameter to assess the damage. This study relates the reduction in FVC due to exposure duration and RSPM concentration.

Methodology

The sand stone quarrying process is done manually and mechanically but the involvement of workers in both the cases is significant. There are three types of workers:

- (a) *Driller*: Workers employed for drilling, blasting and cutting.
- (b) *Dresser*: Workers employed for doing fine work by chiseling or dressing the stone pieces.
- (c) *Labour*: Employed for loading and unloading operation and exposed to normal quarry environment.

The various steps involved in methodology:

- i. Selection of quarries: Quarries of different areas around Jodhpur were selected.
- ii. Selection of Workers: Three types of quarry workers and control population (Workers from same socio-economic group but not exposed to quarry environment) were selected and these workers were categorized depending upon exposure duration.
- iii. Questionnaire: ATS-DLD (American Thoracic Society –Division of Lungs Diseases of National Heart & Lungs Institute of America) questionnaire was modified as per local requirement and prepared in “Hindi” language. The workers were reluctant to disclose information related to personal hygiene.
- iv. Measurement of Particulate Concentration: Particulate concentration were measured with “Respirable High Volume Sampler” (APM-451 Model manufactured by Enviro-tech New Delhi-India)
- v. Measurement of Forced Vital Capacity: Spirometer used for the measurement of FVC was “Spiroweb” manufactured by drc dreicare- Hyderabad-India.
- vi. Statistical Analysis: Statistical analysis was done to check the significance of exposure duration and particulate concentration on decrease in FVC. It was also done to investigate the significance of the difference between the decrease in FVC of two Population (exposed population and controlled population)

Observations

The study was conducted on 476 workers, out of these 455 workers data were recorded and remaining 19 worker’s data were lost owing to file damage in computer. Only 419 data were used for the study purposes and rest was discarded due to various reasons. Only male workers were considered for the study because female worker’s percentage in the stone quarrying industry is negligible. Air particulate samples were collected and Respirable Particulate Matter was collected on 8 x 10-inch glass fibre filters for different activities. Air sampling was carried out at every mine and the average RSPM concentration was calculated for different activities. These activities are designated as loading, dressing and drilling and the workers who perform these works are called labour, dresser and driller respectively. The concentrations of these activities are designated as 1, 2, and 3 for normal quarry environment (i.e. loading), dressing and drilling respectively. The forced vital capacity (FVC) of workers engaged in different type of activities was measured with the help of Spirometer. The predicted value of forced vital capacity (FVC_p - it depends upon height, weight and age of human) of each worker was calculated by using ERS - 93 Equations. The table 1 gives the average value of RSPM.

Table 1: Particulate concentration for different activities

S.N.	Activity	Particulate Concentration	Concentration category
1	Normal Quarry Environment	4800 µg/m ³	1
2	Dressing	9300 µg/m ³	2
3	Drilling	18500 µg/m ³	3

The control population was selected from the society of same socioeconomic status but these workers were not exposed to mine environment but they are exposed to normal ambient environment. The effect on respiratory tract is chronic therefore exposure duration was divided in four categories, 0-5 yr., 5-10 yr., 10-15 yr. and >15 yr. and these categories are designated as 1, 2, 3 and 4 respectively. Categories of workers, number of workers in each categories and exposure categories are given in table 2 and age wise distribution of quarry worker is given in table 3.

Table 2: Category of workers and exposure duration

Category of Workers	Exposure Duration in Years	Number of Workers	Exposure Category
Labour (132)	0-5	26	1
	5-10	31	2
	10-15	29	3
	>15	46	4
Dresser (126)	0-5	27	1
	5-10	33	2
	10-15	31	3
	>15	35	4
Driller (116)	0-5	26	1
	5-10	33	2
	10-15	28	3
	>15	29	4
Control workers	-----	45	-----

The reduction in forced vital capacity of lung is calculated and it is designated as IFVC and is given by Eq 1. The value of FVCp is calculated by ERS-93 Equation (i.e Eq 2 & Eq 3) [8]. The mean values of index (IFVC) are shown in table 4. The FVC and other required parameters (i.e. height, weight, age and sex) of 419 workers were recorded out of which 374 were quarry workers and 45 were in the category of control population.

Table 3: Age wise distribution of workers

Age Group	% in Quarry Workers	% in Control Population
< 20 Yr.	15.78	24.44
20-30 Yr.	42.51	26.67
30-40 Yr.	28.34	33.33
40-50 Yr.	10.43	8.89
>50 Yr.	2.94	6.67

Table 4: Mean values of index

No .of workers	Worker Category	EXP DUR	EXCAT	PCAT	Mean IFVC
26	Labour	0-5	1	1	0.5296
31	Labour	5-10	2	1	0.5351
29	Labour	10-15	3	1	0.5317
46	Labour	>15	4	1	0.5884
27	Dresser	0-5	1	2	0.5384
33	Dresser	5-10	2	2	0.5726
31	Dresser	10-15	3	2	0.6176
35	Dresser	>15	4	2	0.6448
26	Driller	0-5	1	3	0.5969
33	Driller	5-10	2	3	0.6469
28	Driller	10-15	3	3	0.6483
29	Driller	>15	4	3	0.6734
45	Control Population	---	---	---	0.3209

$$IFVC = (FVC_p - FVC) / FVC_p \quad \text{----- (1)}$$

(A) Males (>18 years):
 $FVC_p = 0.0576 \times H - 0.026 \times A - 4.34 \quad \text{----- (2)}$

(B) Males (<18 years):
 $FVC_p = 7.9942 - 0.12509 \times H + 0.000605 \times H^2 \quad \text{----- (3)}$

Regression Analysis for IFVC

The mean values of index IFVC are calculated for various cases and are shown in Table 4. A multiple linear regression model with dependent variable *Y* and independent variables *X*₁ and *X*₂ is considered [4]:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \quad \text{----- (4)}$$

Where β_0 , β_1 and β_2 are constants and are known as the parameters of the model. The dependent variable IFVC is denoted by 'Y'. The independent variables EXCAT (i.e. exposure categories of workers) and PCAT

(i.e. particulate concentration categories) are denoted by X_1 & X_2 respectively. The regression analysis is done by using the data from Table 4. Let the estimates of β_0 , β_1 and β_2 are denoted by b_0 , b_1 and b_2 respectively. The values of b_0 , b_1 and b_2 are obtained by the principle of least squares. The data given in table 4 are analyzed and calculated statistical parameters are given in table 5.

Table 5: Values of Statistical parameters

Statistical Parameter	Values
R	0.961
R –Square	0.924
F	55.006
b_0	0.435, (t=27.243)
b_1	0.02526, (t=6.131)
b_2	0.04801, (t=8.510)
Std. error of the estimate	0.0159579

Analysis of Variance for Regression

Analysis of variance helps to test whether each of the parameters β_1 and β_2 of the multiple regression models is ‘zero’.

$$H_0: \beta_1 = \beta_2 = 0 \text{ against } H_1: \text{not all } \beta_k = 0: (k=1, 2)$$

Table 5 gives the value of calculated ‘F’: $F = 55.006$ and $F_{k, n-k-1, \alpha} = 8.02$

$$\text{Here } F > F_{k, n-k-1, \alpha}$$

Hence reject H_0 at α level of significance, therefore significance of individual β_s be tested by ‘t – test’.

T-test (for Testing Individual β 's of Multiple Linear Regression Model)

$$H_0: \beta_j = 0 \text{ against } H_1: \beta_j \neq 0: (j=1, 2)$$

The calculated values for ‘t’-statistic for β_1 and β_2 are given in Table 5:

$$t \text{ (for } \beta_1) = 6.131$$

$$t \text{ (for } \beta_2) = 8.510$$

$$\text{The value of } t_{n-k-1; \alpha/2} = 2.26.$$

Here $t > t_{n-k-1; \alpha/2}$; therefore reject H_0 .

Hence $\beta_1 \neq 0$ and $\beta_2 \neq 0$

As the estimated b_0 , b_1 and b_2 are:

$$b_0 = 0.435$$

$$b_1 = 0.02526$$

$$b_2 = 0.04801$$

The estimated multiple regression equation for IFVC is:

$$Y = 0.435 + 0.02526 X_1 + 0.04801 X_2 \text{ ----- (5)}$$

The value of R^2 is 0.924 which means that about 92 % of variation in the dependent variable Y (IFVC) is due to independent variables X_1 and X_2 .

Significance Test for Mean IFVC (For Two Population Means)

To investigate the significance of the difference between the means of two populations viz. exposed and controlled for IFVC; t-test and Cochran-cox test are applied. The t-test for two independent samples is applied when variances of both the populations (exposed and controlled) are unknown but equal whereas the Cochran-cox test is applied for the same, when the variances of both the populations are unknown and unequal. The choice between t-test and Cochran-cox test depends on whether variances of both the populations are equal or not. That is the equality of variances of both the populations can be tested by F-test (Variance Ratio Test).

For IFVC the values of various test statistics: F, t, and Cochran-cox statistic, for different category of workers and controlled population are given in Table 6. First F-test is applied for all the cases to test whether the variances of both the populations are equal. The value of F- statistics is given in column (6) of the table. If the value of F-statistics is significant (such values are marked with *) the Cochran –cox test is applied and the value of test statistics t_c , for different cases are given in col. (13). Whereas, if value of F-statistic is insignificant then t-statistics for different cases, are calculated and its values are given in col. (9). Significant values of these statistics are marked with *. The critical values for F and Cochran-cox tests are given in cols. (7) and (12). The critical value of ‘t’ i.e. $t_{n_1 + n_2 - 2; \alpha}$ is taken as 1.96 (i.e. for normal distribution).

It is observed from the Table 6, that the values of ‘t’-statistics or Cochran-cox test statistics, as the case may be are significant for all the cases. Thus it is concluded that there is significant difference between the mean indices for exposed & controlled populations for IFVC.

Noting further that the mean values of concerning index for exposed population is considerably higher than the corresponding value of control population. Therefore, it indicates that forced vital capacity of lungs of stone quarry workers are reduced due to the particulate pollution in quarries.

Table 6: Tests for equality of means of exposed and control population for IFVC

Worker Cat	Excat	n	MIFVC	VRIFVC	F	$F_{v1, v2, 0.05}$	S_p	t	w_1	$t_{1\alpha/2}$	t_{cr}	t_c	TEST
Labour	1	26	0.5296	0.01149	1.119	1.753	0.01116	75.9288*	-----	-----	-----	-----	t-test
Labour	2	31	0.5351	0.01180	1.142	1.720	0.01131	81.1394*	-----	-----	-----	-----	t-test
Labour	3	29	0.5317	0.01881	1.823*	1.733	-----	-----	0.00067	2.0480	2.0394	6.98895	Cochran-Cox
Labour	4	46	0.5884	0.01989	1.900*	1.645	-----	-----	0.00044	2.0160	2.0157	10.25850	Cochran-Cox
Dresser	1	27	0.5384	0.00296	3.477*	1.838	-----	-----	0.00011	2.0560	2.0283	11.59480	Cochran-Cox
Dresser	2	33	0.5726	0.01304	1.261	1.708	0.01186	92.5894*	-----	-----	-----	-----	t-test
Dresser	3	31	0.6176	0.01957	1.889*	1.720	-----	-----	0.00065	2.0420	2.0348	9.94380	Cochran-Cox
Dresser	4	35	0.6448	0.01306	1.258	1.696	0.01190	120.764*	-----	-----	-----	-----	t-test
Driller	1	26	0.5969	0.00295	3.481*	1.858	-----	-----	0.00012	2.0600	2.0299	14.63055	Cochran-Cox
Driller	2	33	0.6469	0.00561	1.855*	1.752	-----	-----	0.00018	2.0360	2.0239	16.03562	Cochran-Cox
Driller	3	28	0.6483	0.01018	1.006	1.824	0.01065	127.712*	-----	-----	-----	-----	t-test
Driller	4	29	0.6734	0.00612	1.689	1.798	0.00901	164.340*	-----	-----	-----	-----	t-test
Control Population		45	0.3209	0.01047	-----	-----	-----	$w_2=0.00024$		$t_{2\alpha/2}=2.0150$	-----	-----	-----

The critical value of 't' i.e. $t_{n1+n2-2, \alpha}$ is taken as 1.96 (i.e. for normal distribution)

* Significant values of the test statistic under consideration.

Conclusions

The study was carried out to find the effect of particulate concentration on forced vital capacity of lungs of stone quarry workers. The results indicates that as the exposure duration increases the forced vital capacity of lungs decreases and the same times if exposure duration is same but concentration of particulate matter increases then again the forced vital capacity of lungs decreases. Therefore the decrease in the forced vital capacity of lungs depends upon the exposure duration and particulate concentration. The equation developed for the decrease in forced vital capacity of lungs of stone quarry workers is given as Eq 5 and the validity of the equation is tested statistically. The analysis indicates that decrease in the forced vital capacity of lungs of controlled population and affected population has significant difference and this is because of working in the polluted atmosphere and this significance difference is statistically verified. It is revealed from this study that if the exposure duration is more than 15 years then the decrease in forced vital capacity of lungs is approximately 60 % and the workers are suffering from silicosis and many more respiratory problems. The age wise distribution indicates that the about 43 % workers belongs to age group of 20-30 years, about 28% workers belongs to age group of 30-40 years. Workers more than 40 year of age are only about 14 %.

After the age of 40 years workers are suffering from many respiratory problems and they are unable to work.

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