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Effect of Ambient Air Pollution on Forced Vital Capacity of Lungs - A Case Study of Jodhpur City

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Abstract The capacities of lungs depend on the age, height, weight, surroundings, work culture, style of living etc. Most important external parameter which has direct impact on physical and mental well being of urban residents worldwide is presence of air pollutants in the surroundings. Air pollutants get entry in the human body through inhalation and affect respiratory system. They interfere with the natural metabolic and other activities of human body. Due to damage of respiratory system various Pulmonary Function Values are reduced. The objective of present study is to co-relate Spirometric abnormalities with duration of exposure and Air Quality Index and to assess the reduction in lung capacity in terms of reduction of Forced Vital Capacity (FVC). The study is done at various locations of Jodhpur City, India. The study reveals that the 'Forced Vital Capacity' of lungs decrease as the Exposure Duration increases as well as the pollutants concentration increases. The estimated multiple regression equation for Reduction in forced vital capacity (i.e. Index for FVC) is developed as $Y_F = 0.053X_1 + 0.003X_2 - 0.197$. The calculated values of 'y_F' give direct indication of damage severity without any medical or Pulmonary Function Test. The values y_F will be in between 0 to 1. If the value is more, this means the damage intensity is very high.

Keywords: *lung capacity, Forced Vital Capacity (FVC), SO_2, NO_2, AQI, multiple regression analysis, Pulmonary Function Test, ANOVA, Particulate Matter (PM)*

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1. Introduction

Air Pollution has a major impact on the physical & mental well being of urban residents worldwide. The air pollutants get entry in the human body through inhalation. They damage the respiratory system and interfere with the natural metabolic and other activities of human body. Due to damage of respiratory system various "Pulmonary Function Values" are reduced. The present study is conducted at Jodhpur City to assess the reduction of Forced Vital Capacity of residents due to ambient air pollution. FVC is the volume of air a person exhales with forceful expiration after maximal inspiration. Normally it is reached within 3-4 seconds but airway obstruction prolongs this time [6].

The 'Surya Nagari' Jodhpur is the second largest city of Rajasthan (India) and the Gateway of famous 'Thar Desert' inhabitating a population of 8, 56,034 according to 2001 census. Jodhpur is situated on northwestern border of Rajasthan. The increased Army/Air Force, Industrial, Trade & Commerce and Tourism activities have led to expansion and growth of the city and other related economic activities up to a great extent. Although there are more than 100 pollutants, which are broadly classified into two categories which are Particulate Matter and Gases. Here we are concerned with few important pollutants like Respirable Suspended Particulate Matter (PM_{10}), SO_2, and NO_2 only. Many environmental cum medical studies have been carried out worldwide to establish a link between different type of pollutants, respiratory diseases and level of pollution that would significantly affect human health. The acute health effect of suspended particulate matter (SPM), even at short term low levels exposure; include increased daily mortality and hospital admission rates for exacerbation of respiratory disease [5]. Long term exposure to $PM_{2.5}$ increases the risk of the non-accidental mortality. Living close to busy traffic appears to be associated with elevated risk [2]. The available human clinical results do not establish a mechanistic pathway leading to adverse health impacts for short term NO2 exposure at present day ambient environment [3]. In all the analytical studies total mortality was directly associated with long term exposure to particulate matter [4]. Each day our lungs are directly exposed to more than 7000 liters of air, which contain varying amount of inorganic, organic particles and various types of gases. Hence it is required to assess the damage on the basis of air quality of the area. In this case study, relationship between severity of the damage (in terms of reduction in lung capacity) & exposure duration and concentration of pollutants (in terms of Air Quality Index) has been established.

2. Methods and Methodology of Case Study

As per EPA guidelines concept of Air Quality Index (AQI) has been adopted. The AQI of different locations of Jodhpur has been determined to select the various spots for study. On these particular spots the most affected persons were selected for the study on the basis of their continuous exposure. The respiratory parameter considered in the study was Forced Vital Capacity (FVC) and it was measured with the help of computerized Spirometer. Fine Particulate Sampler and High Volume Sampler were used in this study to measure the concentration of various pollutants considered in study. AQI was determined on the basis of concentration of pollutants.

2.1. Observations, Calculations and Analysis

Various observations for SO_2, NO_2 and PM_{10} were taken at selected locations of Jodhpur. Amongst them the following four sites were selected as shown in Table 1 whose annual mean values were highest.

From these concentrations of the pollutants, value of sub-indexes of respective pollutants was calculated to predict AQI. The formulae for sub-indexes calculation are depending on the range of concentration of respective pollutant and are given in Table 2.

The highest value of sub-indexes for various pollutants for that sampling station is considered as AQI for that particular sampling station and is given in Table 3.

Table 1. Annual Mean values of pollutants measured at various sampling stations

Sampling Stations No.	Location in Jodhpur	Parameters		
		SO_2 (μgm/m^3)	NO_2 (μgm/m^3)	PM_{10} (μgm/m^3)
1	Ratanada Bazar Circle	8.4	16.23	95.0
2	Akhliya Circle	11.87	18.16	115.0
3	Jalori Gate Circle	14.19	22.29	129.0
4	Nai Sarak – Sojati Gate Chauraha	21.19	24.66	143.0
Note- Periods of sand storms and rainy days were discarded.				

Table 2. Formulae used for sub-index calculation at different concentration of pollutant [1]

Pollutant	Concentration (X)	Formula
SO_2	$X < 40$	Sub-Index = 2.386363 X
	$X \geq 40$	Sub-Index = 1.6178737 (X-40) +100
NO_2	$X < 60$	Sub-Index = 1.666666 X
	$X \geq 60$	Sub-Index = 0.6220754 (X-60) +100
PM_{10}	$X \leq 50$	Sub-Index = X
	$50 < X \leq 150$	Sub-Index = 0.500000 (X-50) + 50
	$X > 150$	Sub-Index = 0.936768 (X-150) +100

Note: 1 Average concentration based on 24 hours (In ppb)
2. The formula for AQI for SPM has been used for calculating AQI for RSPM i.e. PM_{10}. The readings for SO_2 are calculated in μgm/m^3. In above formula concentration of the pollutant are in ppb but we measure in μgm/ m^3 so that we convert this using Ideal Gas Law for SO_2 (1 μgm/m^3 = 0.381807252 ppb), for NO_2 (1 μgm/m^3 = 0.534413876 ppb).

Table 3. AQI value at different sampling station

Sampling Stations No.	Parameters and Sub-Index			AQI
	SO_2 (μgm/m^3)	NO_2 (μgm/m^3)	PM_{10} (μgm/m^3)	
1	7.66	14.46	72.5	72.5
2	10.82	16.17	82.5	82.5
3	12.93	19.86	89.5	89.5
4	19.31	21.96	96.5	96.5

After determination of AQI the exposed persons were selected at different point for determining the reduction in FVC. The selection of persons was based on exposure duration (1 to 5 years of exposure, minimum exposure 8 hours or more each day). Persons having hereditary/ previous respiratory diseases, smoking habits, chewing of tobacco & alcoholic etc. were not taken for study. The control population were selected who were not exposed /little exposed to such environment for comparison purpose.

The Pulmonary function parameter FVC was measured for all the selected persons. The study subjects were divided in various categories depending upon their exposure duration. The predicted values of FVC, is calculated by using ERS-93 equation. Predicted values are designated as FVC_P. The age (A), height (H) and weight of every person were recorded for the calculation of predicted value of FVC.

For Males (> 18 years):

$$FVC_P = 0.0576H - 0.026A - 4.34 \quad (1)$$

Index is developed to find out the extent of damage and percentage of volume reduction in fraction. This Index is designated as IFVC which is calculated with the help of following formulae:

$$IFVC = (FVC_P - FVC) / FVC_P \quad (2)$$

The Pulmonary function parameter FVC was measured for different persons for their different exposure duration at all sampling station. Numbers of observations for different exposure duration and for different AQI are given in Table 4 and Table 5. Mean values of IFVC (Index that represent extent of damage) is calculated for each case and is given in Table 4 and Table 5.

For the controlled population (population which was not exposed to urban pollution but belongs to same class of society) total 38 numbers of observations was taken and mean value of IFVC was calculated and which was found to be 0.037.

Table 4. Mean Values of IFVC for 1, 2 & 3 years exposure

AQI	1 Yr. Exposure		2 Yr. Exposure		3 Yr. Exposure	
	No. of Obs.	Mean IFVC	No. of Obs.	Mean IFVC	No. of Obs.	Mean IFVC
72.5	27	0.0530	27	0.0900	28	0.1685
82.5	29	0.0612	29	0.0994	27	0.1766
89.5	27	0.0814	30	0.1326	28	0.2100
96.5	36	0.1327	34	0.1735	29	0.2216

Table 5. Mean Values of IFVC for 4 and 5 years exposure

AQI	4 Yr. Exposure		5 Yr. Exposure	
	No. of Obs.	Mean IFVC	No. of Obs.	Mean IFVC
72.5	26	0.2065	27	0.2600
82.5	28	0.2352	27	0.2873
89.5	35	0.2453	32	0.2968
96.5	28	0.2570	27	0.3100

Data shows the increasing trend for all the cases, which is not truly linear but most appropriate relation to represent this increasing trend is linear only. Hence the multi – linear Regression analysis is done for IFVC and significance tests are applied to verify the consistency & significance of all the parameters of the multiple regression models as under:

Table 6. Model summary

Model	R	R^2	Std. error of the Estimate
IFVC	0.989	0.979	0.01243

'R' is multiple co-relation coefficients. As the value of R is positive (from ANOVA Table) it is a positive co-relation. 'R2' is coefficient of determination whose value is 0.979. It indicates that two independent variables Exposure Duration (EXDUR) and Air quality index (AQI) jointly account for the variation in IFVC up to 97.9% and remaining 2.1% variation is due to other reasons.

Table 7. ANOVA (Dependent Variable: IFVC)

IFVC	Sum of squares	df	Mean square	F
Regression	0.121	2	0.061	305
Residual	0.003	17	0.0002	
Total	0.124	19		

$$H_o : \beta_1 = \beta_2 = 0 \;\&\; H_1 : \text{ not all } \beta_k = 0 (\text{For k} = 1, 2)$$

Where, d.f. is 'degree of freedom', and F is 'Ratio of Mean Squares'

ANOVA Table 7 gives the value of calculated value of $F_{calculated}$.(i.e. F=305) and critical value of F from standard tables (i.e. $F_{k, n-k l, \alpha}$=3.59).

Here, $F_{calculated} > F_{k, n-k-l, \alpha}$, Hence, reject H_0 at α (= 0.05) level of significance, therefore significance of individual β's be tested by't - test'.

Table 8 Coefficients (Predictors: (Constant), AQI, and EXDUR)

IFVC	Coefficients		t
	b	Std. Error	
Constant	-0.197	0.028	-7.154
EXDUR	0.053	0.002	26.750
AQI	0.003	0.0002	8.39

$$H_0 : \beta_j = 0 \;\&\; H_1 : \beta_j \neq 0 : (j = 1, 2)$$

Where, Std. Error is 'Square root of ratio of Sum of Squares to Category of Samples' and t is 'ratio of Parameters difference (calculated value minus value from std. tables) to Standard error'.

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 = -0.197, b_1 = 0.053 and b_2 = 0.003, hence finally estimated multiple regression equation for IFVC that relate the severity of damage to the exposure duration and air quality index can be expressed as:

$$Y_F = 0.053X_1 + 0.003X_2 - 0.197$$

Where
Y_F = IFVC
X_1 = Exposure duration
X_2 = Air Quality Index

3. Conclusion

The quality of air in Jodhpur is worsening day by day due to increase of air pollutants concentration. Although the level AQI which is recorded as 'Moderate' (AQI < 100) but reduction in forced vital capacity of lungs for exposure duration of 5 years is significant. Data indicated that as the Exposure Duration increases the percentage reduction in forced vital capacity of lungs increases. It also shows that the value of AQI index increases the reduction of forced vital capacity of lungs increases. It is revealed from the study that exposure duration and air quality both is responsible for reduction of vital capacity of lungs. The significant reduction in IFVC is due to air pollutants because the reduction is negligible in control population. It reflects that the 'Forced Vital Capacity' of lungs decrease as the Exposure Duration increases as well as the pollutants concentration increases.

The estimated multiple regression equations directly gives relationship between decrease in vital capacity of lungs, exposure duration and air quality index.

$$Y_F = 0.053X_1 + 0.003X_2 - 0.197$$

The calculated values of 'Y_F' give direct indication of damage severity without any medical or Pulmonary Function Test. The values y_F will be in between 0 to 1, if the value is more, this means the damage intensity is very high. Hence from the developed equation, reduction in vital capacity of lungs can be calculated.

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