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ASSESSING RESPIRATORY MORBIDITY THROUGH POLLUTION STATUS AND METEOROLOGICAL CONDITIONS FOR DELHI

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Abstract. The study focuses on assessing the status of respiratory morbidity in Delhi over a four years period from 2000–2003. An attempt was made to investigate the role of important pollutants (SO_2, NO_2, SPM and RSPM) and various meteorological factors (temperature minimum & maximum, relative humidity at 0830 and 1730 hrs. and wind speed) in being responsible for respiratory admissions on account of COPD, asthma and emphysema. The study showed that winter months had greater exposure risk as pollutants often get trapped in the lower layers of atmosphere resulting in high concentrations. Statistical analysis revealed that two pollutants have significant positive correlation with the number of COPD cases viz., SPM ($r = 0.474$; $p < 0.01$) and RSPM ($r = 0.353$; $p < 0.05$), while a meteorological factor temperature (minimum) has a significant negative correlation ($r = -0.318$; $p < 0.05$) with COPD. Stepwise multiple regression analysis was performed for COPD as dependent variable and R^2 value of 0.33 was obtained indicating that SPM and RH(1730) were able to explain 33 percent variability in COPD. The partial correlation of SPM and RH(1730) on COPD was higher than any other combination and therefore they can be regarded as important contributing variables on COPD.

Keywords: air pollution, COPD, meteorological factors, respiratory morbidity, SPM

Abbreviations: COAD or COPD, Chronic Obstructive Airway/Pulmonary Disease; CPCB, Central Pollution Control Board; RH(0830) and RH(1730), Relative Humidity at 08:30 and 17:30 hours; WS, Wind Speed; IMD, India Meteorological Department; SO_2, Sulfur dioxide; NO_2, Nitrogen dioxide; SPM, Suspended Particulate Matter; RSPM, Respirable Suspended Particulate Matter (PM $<10\ \mu$m. in size); NAAQS, National Ambient Air Quality Standard

1. Introduction

Researchers from all parts of the world are exploring the toxicological, clinical and epidemiological effects of air pollutants especially among the vulnerable groups – asthmatics, chronic obstructive pulmonary disease (COPD) patients, patients with poor/impaired lung function and immune response, patients with coronary artery disease and other cardiovascular problems, as well as in children (Penttinen *et al.*, 2001; Niphadkar *et al.*, 2000; Zielinski *et al.*, 2001; Sharma and Pandey, 1995; Bethel *et al*., 1983; Wright, 1988; Last *et al*., 1988). Acute health effects of breathing polluted air are recognized world over, ranging from increased cardio respiratory morbidity and mortality to increased prevalence of respiratory symptoms and decrements in lung function (Lahiri *et al*., 2000; Kumar, 1999; Pennington, 1988; Bascom *et al*., 1996; WHO publication, 1982; Sheppard, 1987). Association between air pollution and (a) variation in mortality, (b) incidence of certain cancers, (c) hospital admissions and emergency visits, and (d) decreased pulmonary function have been reported in several studies (Wong *et al*., 2001; Pande *et al*., 2002; Zemp *et al*., 1999). According to the World Health Report 2002, analysis based on particulate matter estimate that ambient air pollution causes about 5% of trachea, bronchus and lung cancer, 2% of cardio-respiratory mortality and about 1% of respiratory infections mortality globally. This amounts to about 1.4% (0.8 million) deaths and 0.8% (7.9 million) of disability adjusted life years (DALY).

In India, premature deaths have been reported to have occurred due to air pollution. Cropper *et al*. (1997) has associated an increase in particulates with a 2.3% increase in deaths in Delhi. A health study in Mumbai showed a higher morbidity in subjects residing in areas with raised levels of pollutants (Kamat and Doshi, 1987). Lahiri *et al*. (2000), have also found a marked increase in respiratory symptoms (43% in urban and 14% in rural) and sputum alveolar macrophages of children residing in urban areas of Calcutta city. According to a study conducted in 10 schools of Delhi 11.9 percent were asthmatic while another 3.4% showed symptoms of asthma earlier (Chhabra, 2002). The deteriorating air quality was implicated as one of the major causative factors. Pande *et al*. (2002), have shown that the emergency room visits for asthma, COAD and acute coronary events increased by 20 to 25% on account of higher than acceptable levels of pollutants in Delhi. Thus, with the documented results of the above mentioned studies, it is certain that considerable burden of cardio-respiratory diseases exists due to high levels of ambient air pollution.

Though it is well known that air pollution episodes result in mortality as well as morbidity, the contribution of various pollutants and the role of meteorological factors in aggravating and/or reducing the pollution load as well as disease burden has not been investigated. This study, therefore, is taken up with an objective of estimating those pollutants and meteorological factors that significantly contribute towards various respiratory ailments. We have attempted to find association of respiratory ailments (COPD, Asthma and Emphysema) with pollutants (SO_2, NO_2, SPM and RSPM) and various meteorological factors (Temperature minimum & maximum, Relative Humidity at 0830 & 1730 hours and Wind Speed). Section 2 of the paper gives a brief about the study area, which served as a good source of air pollution data, respiratory patients data and meteorological data. Section 3 details the results pertaining to the seasonality study, correlation and regression analysis. Pollutants and meteorological factors significantly contributing towards COPD have been identified through multivariate regression analysis.

Figure 1. Location of Safdarjung area in Delhi.

2. Materials and Methods

2.1. Study area and health data

A south Delhi – Safdarjung area was selected for study. Figure 1 gives the location of the study area in Delhi city. The area was selected because it is one of the busiest traffic intersections in the city and witnesses high traffic density and emission load. The area also houses one of the most popular government hospitals – Safdarjung hospital. The hospital receives huge influx of patients from various socio-economic classes, largely from lower and middle income groups. Adjacent to the safdarjung area is situated the India Meteorological Department (IMD) which provided with the meteorological data of the study area. Thus, the study area was a good source of all three viz., air pollution data, respiratory patients data and meteorological data. In-patients data on account of respiratory illness (viz., Chronic Obstructive Pulmonary Disease – COPD, Asthma and Emphysema) was obtained from Safdarjung hospital. Monthly data of each of the three diseases was collected over the four years period from 2000–2003.

2.2. Environmental data

In order to get an estimate of the air pollutants concentration in the Safdarjung area, monthly air quality data of the two nearest central pollution control board (CPCB) monitoring stations – ‘Nizamuddin’ and ‘Siri Fort’ was collected over the last four years (2000–2003). Arithmetic mean of ambient air monthly data was obtained after an eight hourly – thrice daily monitoring of the four pollutants viz., sulfur dioxide, nitrogen dioxide, suspended particulate matter and respirable suspended particulate matter. Data was studied to identify the months with the lowest and the highest mean concentrations of pollutants. Meteorological data pertaining to temperature (minimum and maximum), relative humidity (at 0830 and 1730 hours) and wind speed was collected for each month over the four years period (2000–2003) from IMD.

2.3. Statistical analysis

2.3.1. *Seasonality Study for Pollutants with Meteorological Variables*

Monthly analysis of pollutants and meteorological variables was carried out for the past four years (2000–2003) in Delhi. It was observed that the distribution of pollutants was cyclic over the time period 2000–2003. Since, the samples drawn from the parent distribution were not normally distributed therefore some of the analysis was done using non-parametric methods. Seasonality study was performed by grouping each year’s data into four quarters of three months each viz., I (January–March), II (April–June), III (July–September) and IV (October–December). The quarterly data of all four years was then statistically analyzed using SPSS software (statistical package for social sciences). Table I and Figure 2 give the distribution of mean values of the four pollutants and the five meteorological variables amongst the four quarters. The data was further subjected to χ^2 analysis in order to test the equality amongst the four quarters. *Null Hypothesis:* There is no significant difference between the four quarters. All the variables were further subjected to

TABLE I
Quarterly Statistics (mean, standard deviation) for Pollutants and Meteorological variables

Pollutants/Meteorological variables	Quarter I		Quarter II		Quarter III		Quarter IV	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SO_2	16.7	5.5	13.6	2.6	12.8	3.1	14.3	2.8
NO_2	33.1	3.3	30.5	5.3	30.5	4.9	36.5	4.9
SPM	297.5	34.6	398.0	85.6	220.0	78.0	399.0	54.6
RSPM	119.0	19.8	132.0	28.4	75.0	23.4	168.0	40.6
Temp. (max.)	24.1	4.7	38.3	1.7	34.6	1.8	28.6	4.5
Temp. (min.)	10.8	3.5	25.4	2.7	26.3	1.8	13.6	4.8
RH(0830)	78.7	10.7	54.8	11.5	77.5	9.7	77.7	5.6
RH(1730)	47.4	12.5	35.9	14.1	63.8	10.4	54.5	8.6
WS	6.8	1.2	8.2	1.5	7.4	2.5	3.8	1.4

$N = 12$ for all Quarters.

Kruskal-Wallis one way analysis of variance by rank (Daniel, 2000), to identify the quarters with highest and lowest pollution load (Table II). The variation amongst the means of the four quarters for all four pollutants, five meteorological variables and the frequency of the three respiratory diseases is presented in Figure 2.

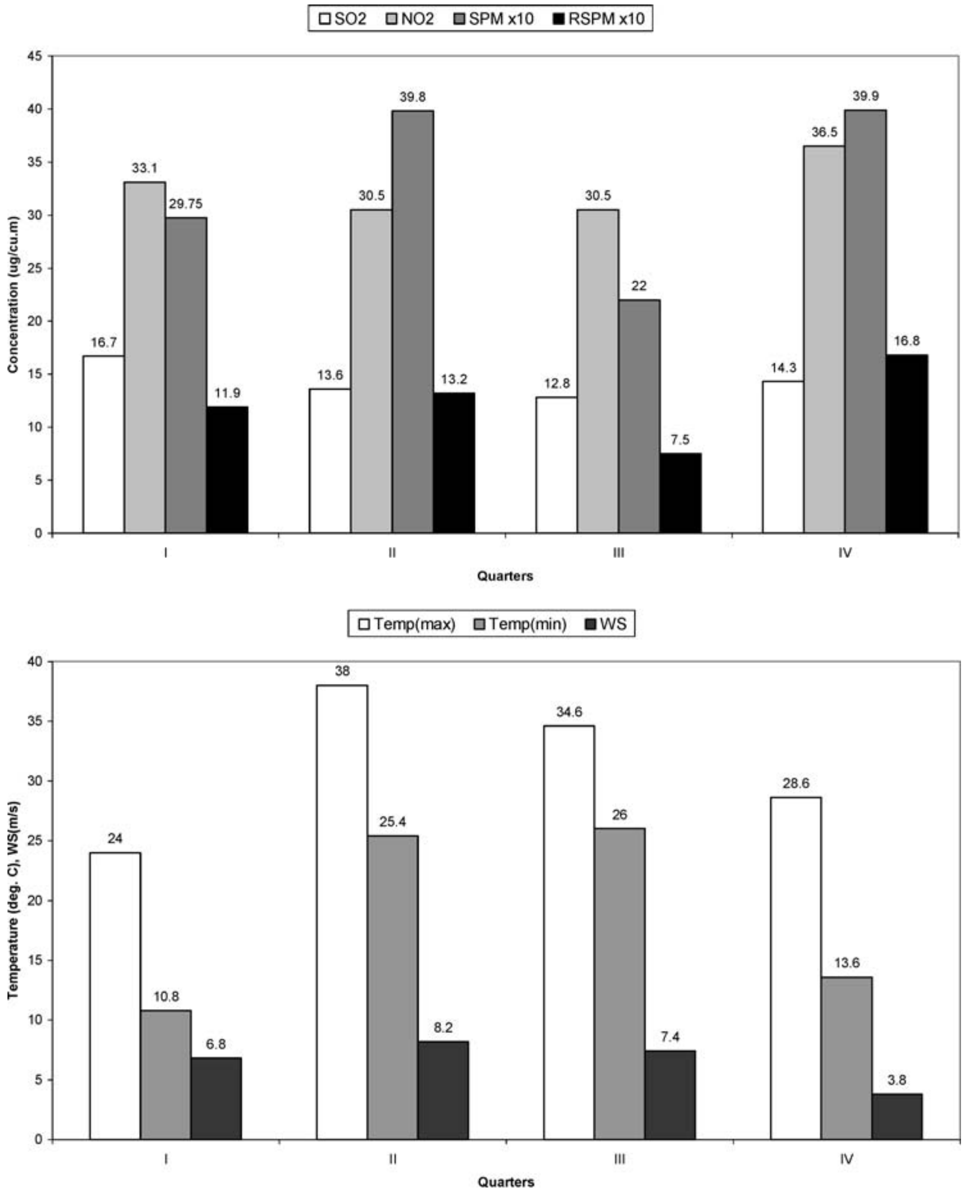

Figure 2. Quarterly average of Pollutants, Meteorological variables and total Respiratory cases.

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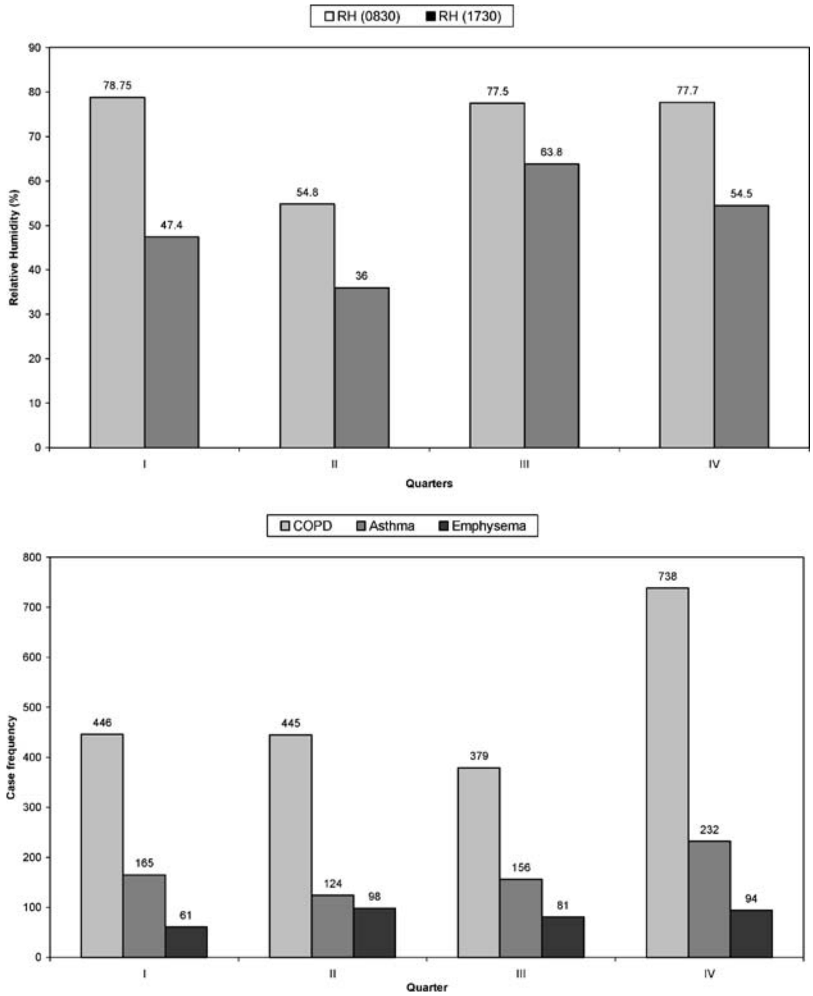

Figure 2. (*Continued*)

2.3.2. *Respiratory Ailments Analysis with Varying Pollutants Levels*

In order to study the variations in the frequency of respiratory admissions (COPD, asthma and emphysema) in different quarters, χ^2 analysis was performed. *Null Hypothesis:* There is no significant difference between the four quarters. All the variables were further subjected to Kruskal-Wallis one way analysis of variance by rank, to get an estimate of the quarters with the highest and lowest patients load. Table III gives the results. χ^2 analysis showed that significant difference (p-value ≤ 0.05) exists for COPD patients only.

Further, in order to study the variations in COPD case frequency with that of the variations in pollutants concentration, monthly average of the four pollutants (SO_2, NO_2, SPM and RSPM) were categorized into Low, Moderate, High and

TABLE II
Kruskal-Wallis one way analysis by rank and χ^2 test of significance for four pollutants and five meteorological variables

	Quarters	*N*	Mean rank	Significance level (*p*-value)
Parameter pollutants				
SO_2	1	12	30.33	0.26
	2	12	22.33	
	3	12	19.50	
	4	12	25.83	
NO_2	1	12	26.21	0.02
	2	12	18.96	
	3	12	18.92	
	4	12	33.92	
SPM	1	12	19.08	0.00
	2	12	34.42	
	3	12	9.67	
	4	12	34.83	
RSPM	1	12	23.29	0.00
	2	12	30.17	
	3	12	9.13	
	4	12	35.42	
	Total	48		
Meteorological variables				
Temp.max	1	12	9.71	0.00
	2	12	41.67	
	3	12	29.92	
	4	12	16.71	
Temp.min	1	12	10.63	0.00
	2	12	35.83	
	3	12	37.17	
	4	12	14.38	
RH 0830	1	12	31.71	0.00
	2	12	8.54	
	3	12	29.54	
	4	12	28.21	
RH 1730	1	12	21.00	0.00
	2	12	11.83	
	3	12	37.33	
	4	12	27.83	
WS	1	12	25.63	0.00
	2	12	36.75	
	3	12	27.63	
	4	12	8.00	
	Total	48		

TABLE III
Kruskal-Wallis one way analysis by rank and χ^2 test of significance, to determine variations amongst four quarters for the three respiratory ailments

Parameter	Quarters	N	Mean rank	Significance level (p-value)
COPD	1	12	23.50	0.05
	2	12	22.46	
	3	12	18.38	
	4	12	33.67	
	Total	48		
Asthma	1	12	23.33	0.07
	2	12	18.17	
	3	12	23.67	
	4	12	32.83	
	Total	48		
Emphysema	1	12	17.83	0.16
	2	12	30.25	
	3	12	23.21	
	4	12	26.71	
	Total	48		

Critical range (as per NAAQS criteria) depending upon their concentration range, for each month from 2000–2003. The mean rank (Table IV) calculated for the COPD cases corresponding to their frequency of occurrence in each of the four categories of SPM and RSPM levels is presented in Figure 3. The COPD case

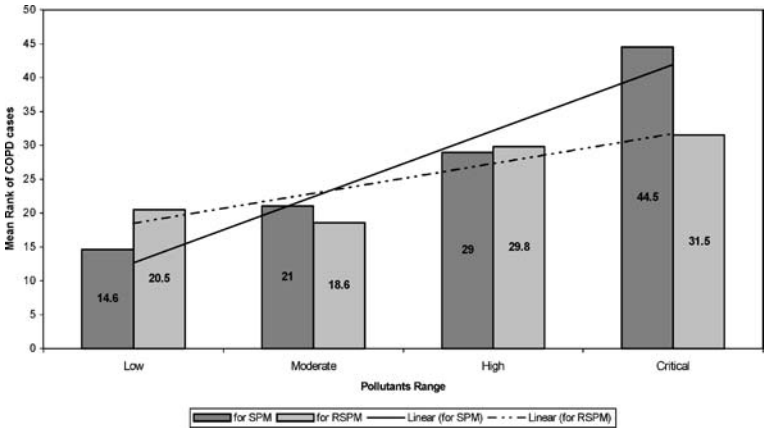

Figure 3. COPD frequency corresponding to SPM and RSPM pollutant category.

TABLE IV
Kruskal-Wallis one way analysis by rank and χ^2 test of significance, to determine variations amongst the COPD cases with varying pollutant categories

Pollutant	Category	N^*	Mean rank	Total COPD cases	Significance level (p-value)
SO_2	Low	48	24.5	2028	–
NO_2	Low	45	23.2	1778	0.017
	Moderate	3	43.2	250	
SPM	Low	4	14.6	101	0.02
	Moderate	24	21.0	874	
	High	18	29.1	886	
	Critical	2	44.5	167	
RSPM	Low	4	20.5	137	0.05
	Moderate	20	18.6	640	
	High	20	29.8	1020	
	Critical	4	31.5	231	
	Total	48		2028	

*N is the number of months in each category (from 2000–2003).

frequencies were then tested for variations (if any) with regard to the four pollutant categories. Chi-square analysis was performed to test distribution of COPD cases in periods of Low, Moderate, High and Critical pollutants load. *Null Hypothesis:* There is no significant difference in the number of COPD cases with respect to the four pollutants categories. Table IV gives the output of χ^2 analysis. Kruskal-Wallis test was performed with regard to NO_2, SPM and RSPM only. Since SO_2 levels were present in only one category (low) all the time, therefore, no analysis could be performed. Also, with regard to NO_2 levels, the distribution was restricted to low and moderate category thereby giving insufficient scope for analysis ($df = 1$, Table IV).

2.3.3. *Correlation and Regression Analysis*

Pearson's coefficient of correlation was calculated to determine linear associations between and amongst the four pollutants (SO_2, NO_2, SPM & RSPM), five meteorological parameters (Temperature-minimum & maximum, Relative Humidity at 0830 and 1730 hours and Wind Speed) and the three respiratory ailments (COPD, Asthma & Emphysema). Table V gives the results of correlation analysis. Multiple regression analysis was carried out for respiratory ailments in order to identify significant pollutants and meteorological factors. Stepwise regression procedure was adopted with COPD as dependent variable and the nine variables viz., SO_2, NO_2, SPM, RSPM, Temperature (minimum & maximum), Relative Humidity (0830),

TABLE V
Correlation matrix on Pollutants, Meteorological variables and Respiratory ailments (Only significant correlations are shown)

	SO_2	NO_2	SPM	RSPM	Temp. Max.	Temp. Min.	RH0830	COPD
SPM				0.771** (48)				
TEMP .MAX.		−0.359* (48)						
TEMP. MIN.	−0.333* (48)	−0.429* (48)		−0.420* (48)	0.924** (48)			
RH0830			−0.482 ** (48)		−0.727** (48)	−0.484** (48)		
RH1730			−0.531** (48)		−0.394* (48)		0.863** (48)	
WS		−0.316* (48)			0.374* (48)	0.449** (48)	−0.399* (48)	
COPD			0.474* (48)	0.353* (48)		−0.318* (48)		
ASTHMA								0.514** (48)

* $p < 0.05$; ** $p \leq 0.01$; Figures in the parenthesis are *n*.

TABLE VI
Multivariate Regression Model (stepwise) for COPD

Model		Unstandardized coefficients			
		B	Std. error	t	Sig.
1	(Constant)	−49.788	24.372	−2.043	.048
	SPM	.189	.043	4.368	.000
	RH1730	.622	.272	2.282	.028

Regression Equation: $COPD = -49.78 + 0.189\,(SPM) + 0.622\,(RH\ 1730)$.

RH (1730) and Wind Speed as independent variables. Table VI gives the results of regression analysis.

3. Results and Discussions

3.1. Seasonality study of pollutants and meteorological variables

The mean values of the four pollutants (Table I) were seen to be very different from each other. While SO_2 and NO_2 were mostly within the prescribed NAAQS limits (viz., 60 μg/m^3; annual average), SPM and RSPM were seen to mostly exceed the NAAQS limits (viz., 140 and 60 μg/m^3; annual average respectively). Seasonality study was performed by grouping each years data into four quarters of three months each viz., Ist (January–March), IInd (April–June), IIIrd (July–September) and IV (October–December). χ^2 analysis showed that significant difference (p-value ≤ 0.05) exists amongst the four quarters for NO_2, SPM, RSPM and all five meteorological factors. Thus, it can be said that the above mentioned parameters show different values in different quarters. Results of Kruskal-Wallis test (Table II) showed that the maximum rank (=34) as well as mean ($\approx$400 μg/m^3) concentration of SPM (Table I) occurs in the 4th quarter, closely followed by the 2nd quarter. While, the minimum rank and mean concentration of SPM occurs in the 3rd quarter (viz., 9.6 and 220 μg/m^3 respectively). RSPM also showed maximum concentration and mean rank in 4th and minimum in 3rd quarter. The maximum rank and mean NO_2 concentration was also seen in the 4th quarter while the minimum occurred in the 3rd and 2nd quarter. The maximum SO_2 values were observed in 1st and the minimum in 3rd quarter. Thus, it was seen that the 3rd quarter (June-August) had the lowest level for all four pollutants viz., SO_2, NO_2, SPM & RSPM.

From seasonality study of the past 4 years it was observed that the maximum pollution load was in winter months (1st and 4th quarter) for the two gaseous pollutants – NO_2 and SO_2, whereas, for the particulates (suspended & respirable), maximum pollutants load was observed in winter as well as peak summer months (4th and 2nd quarters). The reason for this discrepancy can be explained from the fact that high pollution load in winters was due to reduced dispersion on account of low wind velocity (Table I shows lowest WS in the 4th quarter, 3.87 m/s), whereas, high particulate pollution load in summers can be attributed to dust storms, greater wind velocity (highest WS = 8.2 is seen in 2nd quarter) and the north-easterly winds bringing additional burden of particulates from the neighboring state of Rajasthan. Rajasthan state has two-thirds of its area as desert with limited water resources and is located in the north western region. In India, for most part of the year, the wind direction is north-easterly except during monsoons when it becomes south-westerly. Thus, there is huge influx of dust/particulates from Rajasthan, which surrounds Delhi from the north-west and south-west directions.

While on one hand higher wind velocity leads to greater influx of particulates, on the other hand, it also leads to decreased gaseous pollution due to greater dispersion and mixing coupled with the higher boundary layer conditions. All pollutants reported lowest mean values in the 3rd quarter. This can be attributed to the washing out of the pollutants by the seasonal monsoon rains in these months resulting in cleaning up of the atmosphere. Relative humidity was seen to be the highest in the 3rd quarter (Table I). Thus, it can be concluded that maximum pollution load occurs during winter months for all four pollutants while minimum occurs during monsoon months. Winter months therefore have greater exposure risk as pollutants often get trapped in the lower layers of the atmosphere thereby resulting in high concentration.

3.2. Respiratory ailments analysis

Chi-square (χ^2) analysis (Table III) showed that significant difference (p-value ≤ 0.05) exists amongst the four quarters for COPD patients only. Further, χ^2 analysis done with regard to Low-Critical pollutants category (Table IV, Figure 3) showed that significant difference (p-value ≤ 0.05) exists in the number of COPD cases with respect to the four pollutant categories for NO_2, SPM and RSPM. That is, the number of COPD cases occurring in Low, Moderate, High and Critical SPM and RSPM levels were different. Since SO_2 and NO_2 were in low and moderate range, therefore meaningful results could not be obtained. From Kruskal-Wallis test (Table IV) it was seen that for SPM, maximum COPD load (mean rank = 44.5) occurs during critical levels, even though the frequency of occurrence of critical SPM level is less ($n = 2$), followed by high (mean rank = 29.1), moderate (=21) and low (=14.6). The test therefore confirms that in conditions of very high SPM pollution and the frequency of COPD patients is higher and vice-versa. Similarly, for RSPM also, higher COPD mean rank (=31.5) was observed in critical range followed by high, low and moderate ranges, thereby suggesting that RSPM levels also directly affect the frequency of COPD patients.

3.3. Correlation analysis amongst pollutants, meteorological factors and respiratory ailments

Table V presents the significant correlation coefficients. From amongst the four pollutants, significant positive correlation was observed between SPM & RSPM ($r = 0.771$ at p-value <0.01). Only SPM & RSPM were seen to vary in accordance with each other. No significant correlation was observed between the other pollutants, thereby indicating that the levels of SO_2, NO_2 and SPM vary independently. Amongst the five meteorological variables significant correlation was observed between most of the variables. Temperature (maximum) showed significant ($p < 0.01$) negative correlation with Relative Humidity at both 8:30 hrs ($r = -0.727$) and 17:30 hrs ($r = -0.39$). It also showed significant positive correlation with Wind Speed ($r = 0.374$; $p < 0.01$). Almost a perfect positive correlation between maximum and minimum temperature was also seen ($r = 0.924$; $p < 0.01$). Unlike maximum temperature which showed significant correlation with RH at 8:30 and 17:30 hours, minimum temperature showed significant negative correlation with RH at 8:30 hours only ($r = -0.484$; $p < 0.01$). Significant ($p < 0.01$) positive correlation was seen to exist between WS and minimum temperature and a significant ($p < 0.01$) negative correlation was observed between WS ($r = 0.449$) and RH at 8:30 hrs. ($r = -0.399$). Thus, on the whole it can be said that there existed a significant negative correlation between temperature and RH as well as between WS and RH; while there was a significant positive correlation between temperature & WS. With regard to pollutants and meteorological variables, significant negative correlation was seen to exist between the following pairs:- SO_2 and Temperature minimum ($r = -0.333$; $p < 0.05$); NO_2 and (i) Temperature both maximum & minimum, $r = -0.359$; $p < 0.01$ and $r = -0.429$; $p < 0.01$ respectively, (ii) Wind Speed ($r = -0.316$; $p < 0.05$); SPM and RH at both 8:30 hrs and 17:30 hrs ($r = -0.482$; $p < 0.01$ and $r = -0.531$; $p < 0.01$); and, RSPM and Temperature min. ($r = -0.420$; $p < 0.01$).

It can therefore be concluded that significant negative correlation existed between Temperature (minimum) and SO_2, NO_2 and RSPM. This suggests that these three pollutants are influenced by the night time temperature, that is, a rise in minimum temperature would lower their concentration and vice-versa. Also a significant negative correlation was seen to exist between Wind speed and NO_2 and between Relative Humidity and SPM.

Correlation study showed significant positive correlation of COPD with (i) SPM ($r = 0.474$; $p < 0.01$) as well as with (ii) RSPM ($r = 0.353$; $p < 0.05$). A significant positive correlation with SPM & RSPM suggests that the two pollutants have a bearing on the number of COPD cases. None of the pollutants however showed any significant correlation with Asthma and Emphysema. A significant positive correlation was observed between COPD and Asthma ($r = 0.514$; $p < 0.01$), thereby suggesting that the frequency of occurrence of the two respiratory ailments was in tune with each other. However, it was interesting to note that even though the two ailments (COPD and Asthma) and the two pollutants (SPM & RSPM) showed significant correlation with each other, no significant correlation was observed between Asthma and SPM or RSPM. The other two pollutants (SO_2 & NO_2) did not show any significant correlation with COPD. From amongst the various meteorological variables only temperature (minimum) was seen to have significant negative correlation with COPD ($r = -0.318$; $p < 0.05$).

Thus, from correlation analysis it can be concluded that while the two pollutants SPM & RSPM have a direct bearing on the number of COPD cases, a meteorological variable-Temperature min. has an inverse effect. Hence, from the present study it can be said that both SPM and RSPM have maximum bearing on Chronic Obstructive Pulmonary Disease.

3.4. Regression analysis

Multivariate linear regression (with direct method) was performed for COPD with the three independent variables (SPM, RSPM and Temperature min.) as they showed significant correlation with COPD. Following regression equation was obtained at an R square value of 0.312;

$$\text{COPD} = 26.216 + 0.152\,(\text{SPM}) - 0.102\,(\text{RSPM}) - 1.044\,(\text{Temp. min.})$$

Also, a stepwise multivariate regression analysis procedure was selected by taking all nine variables (viz., four pollutants and five meteorological variables). At the end of the iteration procedure, two variables viz., SPM and Relative Humidity (1730 hours) were seen to influence the dependent variable COPD, while all others were excluded. Table VI summarizes the results of the regression model. This model gave a slightly better R-square value (=0.33) with SPM & Relative Humidity (1730) as the independent variables. The following regression equation was obtained:

$$\text{COPD} = -49.78 + 0.189\,(\text{SPM}) + 0.622\,(\text{RH 1730})$$

Thus, a pollutant (SPM) and a meteorological factor (RH 1730 hrs.) are able to explain one-third variability on Chronic Obstructive Pulmonary Disease. It is interesting to note here that even though RH(1730) did not have any significant correlation with COPD, yet it was introduced into the model by stepwise procedure. Its entry into the model can be explained from the fact that it has a strong partial correlation with SPM. Therefore, it can be inferred that though the model is able to explain 1/3rd variability in COPD with SPM & RH (1730), there may be certain other factors contributing towards the remaining unexplained variability. Thus, the stepwise model can be regarded slightly superior than the previous model with the selected variables (SPM, RSPM & minimum Temperature).

4. Conclusion

The study shows that maximum pollution load occurs during winter months for all four pollutants while minimum occurs during monsoon months. SPM and RSPM were seen to always exceed the NAAQS limits. Winter months therefore have greater exposure risk as pollutants often get trapped in the lower layers of the atmosphere thereby resulting in high concentration. From correlation analysis it can be concluded that while the two pollutants SPM & RSPM have a direct bearing on the number of COPD cases, a meteorological variable – temperature minimum has a significant inverse effect. Multivariate stepwise linear regression model explains 1/3rd variability on COPD with SPM & RH(1730), however, there may be certain other factors contributing towards the remaining unexplained variability.

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References

Bascom, R., *et al.*: 1996, 'Health effects of outdoor air pollution, state of the art', *Am. J. Respir. Crit. Care Med.* **153**, 3–50.

Bethel, R. A., Erle, D. J., Epstein, J., Sheppard, D., Nadel, J. A. and Boushey, H. A.: 1983, 'Effect of exercise rate and route of inhalation on sulfur-dioxide-induced broncho-constriction in asthmatic subjects', *Am. Rev. Respir. Dis.* **128**, 592–596.

Chhabra, S. K. and Bhatnagar, S.: 2002, 'Comparison of bronchodilator responsiveness in asthma and chronic obstructive pulmonary disease', *Ind. J. Chest Dis Allied Sci.* **44**, 91–97.

Cropper, M. L., Simon, N. B., Alberini, A. and Sharma, P. K.: 1997, 'The Health Effects of Air Pollution in Delhi, India', World Bank, WPS 1860.

Daniel, W. W.: 2000, *Biostatistics: A Foundation for Analysis in the Health Sciences*, Seventh edition. John Wiley & Sons, New York.

Davis, D. L., Bell, M. L. and Fletcher, T.: 2002, 'A look back at the London smog of 1952 and the half century since', *Environ. Health Persp.* **110** (12).

Estimating Human Exposure to Air Pollutants: 1982, WHO Publication.

Helfand, W. H., Lazarus, J. and Theerman, P.: 2001, 'Donora Pennsylvania: Environmental disaster of the 20th century', *Am. J. Public Health* **91**, 553–554.

Kamat, S. R. and Doshi, V. B.: 1987, 'Sequential health effect study in relation to air pollution in Bombay, India', *Eur. J. Epidemiol.* **3**, 265–277.

Kumar, R.: 1999, 'Effect of air pollution on respiratory system of auto rickshaw drivers in Delhi', *Indian J. Occup. Env. Med.* **3**, 171–173.

Lahiri, T., Roy, S., Basu, C., Ganguly, S., Ray, M. R. and Lahiri, P.: 2000, 'Air pollution in Calcutta elicits adverse pulmonary reaction in children', *Indian J. Med. Res.* **112**, 21–26.

Last, J. A.: 1988, 'Biochemical and Cellular Interrelationships in the Development of Ozone-Induced Pulmonary Fibrosis', in: *Air Pollution, the Automobile, and Public Health*, pp. 415–440.

Niphadkar, P. V. and Pandya, V.: 2000, 'Chronic obstructive pulmonary disease among taxi drivers – an occupational hazard', *Indian J. Occup Env. Med.* **4**, 2.

NAAQS series: 'Air quality in Delhi (1989–2000)', Central Pollution Control Board publication, NAAQS/17/2000-2001, New-Delhi.

Pande, J. N., Bhatta, N., Biswas, D., Pandey, R. M., Ahluwalia, G., Siddaramaiah, N. H. and Khiliani, G. C.: 2002, 'Outdoor air pollution and emergency room visits at a hospital in Delhi', *Indian J. Chest Dis. Allied Sci.* **44**, 13–19.

Pennington, J. E.: 1988, 'Effects of Automotive Emissions on Susceptibility to Respiratory Infections', in: *Air Pollution, the Automobile, and Public Health*, pp. 499–518.

Penttinen, P., Timonen, K. L., Tittanen, P., Mirme, A., Ruuskanen, J. and Pekkanen, J.: 2001, 'Number concentrations and size of particles in urban air: Effects on spirometric lung function in adult asthmatic subjects', *Environ. Health Persp.* **109**(4), 319–323.

Sharma, S. K. and Pandey, J. N.: 1995, 'Air pollution and bronchial asthma', *Indian J Chest Dis. Allied Sci.* **37**(4), 1–5.

Sheppard, D.: 1987, 'Noxious gases: Pathogenic mechanisms', *Environ. Lung Disease*, **V**, 831–846.

World Health Report: 2002, WHO publication.

Wong, C.-M., Stefan, M., Headley, A. J. and Lam, T.-H.: 2001, 'Effect of air pollution on daily mortality in Hong Kong', *Environ. Health Persp.* **109**(4), 335–340.

Wright, J. L.: 1988, 'Relation of Pulmonary Emphysema and Small Airways Disease to Vehicular Emissions', in: *Air Pollution, the Automobile, and Public Health*, pp. 441–463.

Zemp, E. *et al.*: 1999, 'Long–term ambient air pollution and respiratory symptoms in adults (SAPAL-DIA Study)', *Am. J. Respir. Crit. Care Med.* **159**, 1257–1266.

Zielinski, J. and Bednarek, M.: 2001, 'Early detection of COPD in a high risk population using spirometric screening', *Chest* **119/3**, 731–736.