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Seasonal Variation And Dependence On Meteorological Condition Of Roadside Suspended Particles/Pollutants At Delhi

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ABSTRACT

There has been a dramatic improvement in the air quality of Delhi in the recent years presumably due to the implementation of CNG(Compressed Natural Gas) regulation and closure of several polluting industries in the residential areas. This study, carried out from april 2004-march 2005, aims at finding the evidence of these effects and addresses the issue (i) by correlating the pollutants concentrations(SO_2, NO_2, CO, SPM, PM_{10} and O_3) at a roadside in Delhi with the prevailing meteorological variables(temperature, relative humidity, wind speed and direction, rainfall) and (ii) by comparing the recent data of 2004 with that of 1997 prior to the enforcement of land use zoning regulation and changes in policies on vehicular emissions. The study revealed a wide variation in the seasonal distribution of the pollutants. High concentrations of NO_2 and PM_{10} were prevalent(44% of total concentration) during winter while those of SO_2 and SPM were prevalent(42 and 48% of total concentration respectively) during summer. SPM was positively and significantly associated with temperature and wind speed. None of the primary pollutants was found to be significantly correlated with relative humidity whereas O_3 had a significant relation. Based on the results, it can be concluded that the major source of SPM was due to contribution from distant sources whereas the PM_{10} concentration was mainly due to locally generated sources(emissions from vehicles). Major influence of temperature was on NO_2. Comparative study between the two periods- pre-regulation(1997) and post-regulation(2004) imposed by the Government showed remarkable decrease, almost 50%, in the concentration of CO while for NO_2 the situation was almost the same.

KEYWORDS

Pollutant concentration; Meteorological variables; Correlation; Pre and post legislation; CNG.

INTRODUCTION

In urban areas, the largest contribution of primary particles arises from the combustion products of road traffic and industry[1]. Among the anthropogenic sources, vehicular pollution contributes major part of total pollution[2]. Though improvements in vehicle technology play a significant role in reducing traffic emissions at the source, air pollution abatement will remain a challenge because of increasing demand for transportation[3].

The severity of air pollution is determined largely by meteorological factors[4], which can be understood by the fact that the total discharge of contaminants in atmosphere in a particular area remains constant day by day but the degree of pollution may vary widely[5-6]. It is important to understand the relation between meteorological variables and pollutants concentration since strong winds, temperature fluctuations and sand storms can strongly influence the concentration variability. These pollutants, after emission, are dispersed, diluted and subjected to further reactions resulting in the formation of secondary pollutants[2]. A weak level of relation between the air pollution concentrations and wind speeds were found in urban trabzon city, Turkey[7]. Strong relationship among weather conditions as well as local traffic that affected the concentrations of particulates[8] at different site signifies that the correlation values are highly site specific[9]. Statistical analysis of air quality data of Jawaharlal Nehru port and surrounding harbor in navi mumbai found strong inverse relation between particulates and wind speed but weak relation with temperature[10].

The Indian capital Delhi($28^0 38'$N, $77^0 12'$E) is an instructive location for impact of air pollution in an urban area since it is a rapidly expanding centre of government, trade commerce and industry. Recently, Agarwal et al.[11] showed occurrence of maximum pollution loads during winter months which in turn, caused greater exposure risk to human health in Delhi. In recent years, Delhi's air pollution levels have shown dramatic changes primarily due to a series of rulings by the Indian supreme court. Significant among them are the following two rulings: (i)The government of the national capital region(NCR) which includes Delhi, was directed to regulate conversion of all commercial vehicles form diesel/gasoline to clean fuel technology, particularly compressed natural gas(CNG) by march 31,2000, which was further extended until september 30,2001 and then to january 31,2002 by another ruling. (ii)In september 2000, the Indian supreme court directed the closure of polluting industries in residential areas in the so-called 'non conforming areas' as per the delhi development authority's(DDA) guidelines of land-use classification.

The first ruling was enforced strictly and the second, which was met with substantial resistance, is being implemented slowly. It is important to understand the implications of these rulings in terms of their impact on the air quality of Delhi. A comparison of the data of pre legislation days with the post ones is likely to bring out the quantitative changes. In an international seminar on better air quality in manila in 2003, Sengupta[12] reported that there has been 54% reduction in the concentration of SO_2, 42% in CO, whereas there is no change in the concentration of NO_2 from 1996 to 2002. The concentration of SPM has increased by 7% while there is reduction in the PM_{10} concentration by 24%.

The team at the indian institute of technology, Delhi(IITD) has been monitoring the air quality at a roadside in Delhi near the institute for a decade[13-14]. The over all objective of the present paper is (i) to analyze our measured data of primary pollutants i.e. SO_2, NO_2, CO, SPM, PM_{10} and the data for O_3 obtained form central pollution control board(CPCB) to examine seasonal variation in their concentration (ii) to correlate meteorological variables viz. humidity, temperature, rainfall, wind direction and speed with pollutants concentration and (iii) to compare our observed data of CO and NO_2 in 1997 with the present data(2004) and assess how the increases in enforcement of land use zoning regulations and changes in policies on vehicular emissions in Delhi influenced and improved the air quality from vehicular pollution. This will help in better understanding of the changes in urban air quality with respect to the climate of the area.

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EXPERIMENTAL

Study area

The sampling lab is situated inside the Indian institute of technology campus. It is 10km far from the airport, 10km from the city centre and 28m from the main road-the outer ring road. The width of the road is 23.2m. The general layout of the sampling location has been given in figure 1.

There is a boundary wall of 2m height separating the lab from the main road. All types of transport, light and heavy i.e. two and three wheelers, cars, trucks, and buses ply on the outer ring road though the number of cars and two wheelers are more than heavy vehicles. Since there is no major industry in the nearby area, the major sources of pollution are the vehicles. The flow of vehicles during peak hour is given in TABLE 1.

Broadly, throughout the year, Delhi has three distinct seasons:summer(April-june), monsoon(July-september) and winter(November-february). October and march are considered as transition periods and have stable weather conditions with sunny days and occasional precipitation. In the present study, analysis has been done for summer, monsoon and winter seasons. Transition period has not been considered to analyze seasonal variation of pollutants.

Data collection and analysis

SPM and PM_{10} were collected by respirable dust sampler(Envirotech APM 450 BP). Sampling was done every alternate day on working days(3 days a week) from april 2004 to march 2005. The sampler was operated at an air suction flow rate of 1.0-1.2m^3 min^{-1} as per recommended by CPCB[14]. PM_{10}(with aerodynamic diameters smaller than 10μm) were collected on glass fiber paper(GF/A 20.3*25.4cm) whereas SPM was collected in the sampling bottles (cyclone cups) provided with the instrument. The principle employed for the sampling of PM_{10} and SPM is based on the aerodynamic diameters of the particulates. The sampler first separates coarser particles larger than 10μm from air stream before filtering it on the 0.5 micron pore size-filter. Same sampler was used for the sampling of NO_2 and SO_2 with the attachment provided with sampler. Samplings were done 8hr a day at the height of 4m from ground level. For SO_2 and NO_2 sampling, absorbing solution was changed after 4hr duration to maintain the absorbing capacity of solution. 30ml of absorbing solutions were taken in the standard impinges connected to the sampling tube leading form manifold of sampler. The analysis of SO_2 and NO_2 were done the same day following modified West & Gaeke method and modified Jacob & Hochheiser method respectively.

In order to measure CO concentration, APMA-350 E CO monitor (HORIBA) was used. The cross flow modulated analyzer incorporates the basic design features of conventional non dispersive infrared radiation(NDIR) analyzer. The APM-350-E utilizes ambient air, which is filtered through catalyst located inside the instrument as reference gas and to

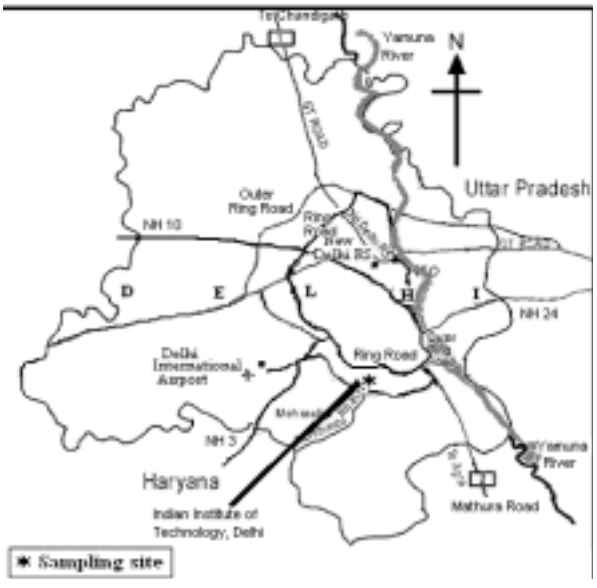

Figure 1: Figure showing the location of sampling site

TABLE 1: Approximate number of vehicles during peak hours i.e., 8-11a.m. and 5-8p.m.

Hours	2-3 wheelers	4 wheelers (light vehicles cars, Jeeps)	4 wheelers (Heavy vehicles, buses)
8-9	1642	1944	138
9-10	2698	2272	192
10-11	2468	2664	234
17-18	2380	2490	332
18-19	3246	2954	262
19-20	2538	2972	176

measure the concentration of CO. The pollutants from ambient air are sucked through glass sampling tube at the height of 4m from the ground surface. Ozone data was obtained from CPCB website (URL:www.cpcb.nic.in). The average value of minimum and maximum concentration was taken for analysis.

The meteorological data was continuously monitored using the weather station installed at the sampling site. The measuring sensors for the meteorological variables were at a height of 10m.

Statistical analysis was done with SPSS package. Pearson correlation was used to obtain correlation coefficients.

RESULTS AND DISCUSSIONS

Trend in meteorological variables

The wind frequency rose diagram for sampling site is shown in figure 2. The highest frequency of winds was observed to be in calm condition i.e. less than 0.5m s^{-1}(56.12%) followed by 0.5-2.1m s^{-1} ranges. The direction of wind was predominantly from the W to WSW & NW and E to ENE during major part of the year.

The monthly mean minimum-maximum temperature and relative humidity is summarized in TABLE 2. The mean relative humidity varied between 38-82%. August was the most humid month and april was the driest. The mean minimum temperature was in the range of(8-27^{0}C) while the mean maximum temperature was in the range of(18.9-38.4^{0}C). The highest temperature was recorded in the month of may (43.4^{0}C). On an average, may was the hottest month (monthly average temperature 31.7^{0}C) and january was the coldest(monthly average temperature 12.7^{0}C).

TABLE 2: Monthly mean ambient air temperature and relative humidity (2004-05)

Month	Air temp. min (^{0}C)	Air temp. max (^{0}C)	R.H (%)
April	22.4	36.5	37.97
May	25.1	38.4	41.65
June	25.7	36.1	56.07
July	27.0	36.2	63.52
August	25.4	32.1	85.06
September	23.9	33.9	69.70
October	18.1	29.6	75.26
November	12.9	27.3	72.53
December	9.9	21.8	79.39
January	8.0	18.9	81.52
February	10.8	22.1	75.93
March	16.9	24.6	66.71

Monthly and seasonal variation in pollutant concentrations (2004-05)

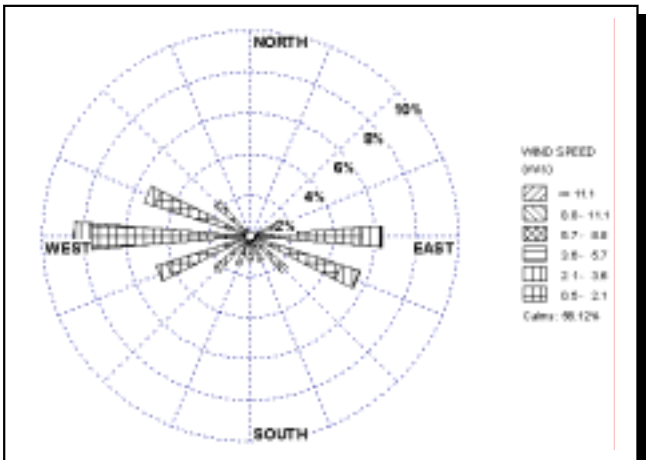

Figure 2: Wind rose frequency showing frequency of prevailing wind speed and direction(2004-05)

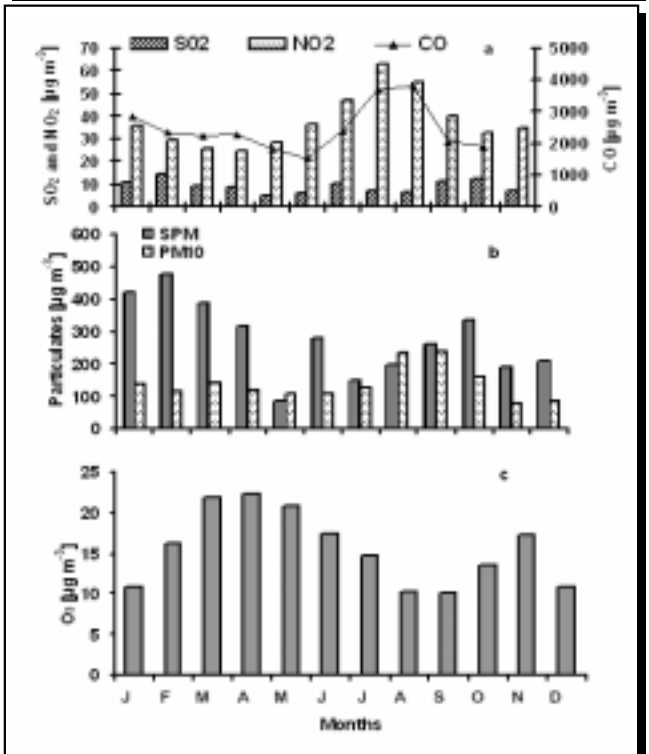

Figure 3: Monthly variation of pollutant concentrations: (a) SO_2 and NO_2 (b) CO, (c)SPM & PM_{10}, (d) Ozone

An average monthly variation of the pollutant concentration is presented in figure 3. The monthly mean concentration of SO_2(Figure 3a) varied from 4.95-14.2μg m^{-3} with maximum value observed on 24th february(20.6μg m^{-3}) and minimum on 12th august(1.4μg m^{-3}). There was remarkable decrease in concentration during month of august from 10th to 17th august(1.4-1.9μg m^{-3}). On the seasonal basis, higher concentration was observed during summer months(April-june) in comparison to others. Earlier observations[16] also observed the mean concentration of SO_2 within the range of 9-12μg m^{-3}. Though it is evident from earlier studies that SO_2 concentration never exceeded the prescribed limit[17], further decrease in the SO_2 trend since last decade may be partly due to the use of low sulphur diesel and reduction in the burning of biomass.

The monthly mean concentrations of NO_2 are shown in figure 3(a). The highest concentration was observed in November(63.4μg m^{-3}). The monthly mean concentration was found in the range of 12.3-63.4μg m^{-3} with highest peak on 2nd december(110μg m^{-3}) and lowest on 3rd august(6.9μg m^{-3}). Downward trend of NO_2 was observed from november to february with further increase in march. The major source of NO_2 are automobiles, mainly the two wheelers, as they account for about two third the total vehicular density and are responsible to emit about 20-40% of fuel burnt/partially burnt. Though the annual average concentration of NO_2 was under the permissible limits(80μg m^{-3}), yet, further control measures should be taken to control its further increase and maintain the air quality. The concentration of CO was in the range of 1820-3810μg m^{-3} increased up to 8860μg m^{-3} in november and the highest concentration was observed during december. On seasonal basis, the concentrations of NO_2 and CO were higher during winter months. The monthly mean concentration of SPM and PM_{10}(Figure 3b) was in the range of 84-474 and 79-237μg m^{-3}. The concentration of particulates was high almost every month except for august and october i.e. during monsoon. SPM concentration was observed to be highest in may followed by second peak in january. The average concentration of particulates always exceeded the prescribed norms(200 and 100μg m^{-3} for SPM and PM_{10} respectively, CPCB) except during monsoon. PM_{10} variation more or less followed a linear trend. In comparison to SPM, the higher concentration of PM_{10} was observed in november and december (236 & 237μg m^{-3}) respectively and lowest in the month of february(79μg m^{-3}). In the last few years, rapid construction of highways and fly overs has contributed in the increased concentration of these particulates in Delhi. But the source of particulates is not only anthropogenic but also the climate and natural sources. As during summer and monsoon period, frequent changes in wind speed and direction were observed which created turbulence in the atmosphere. This resulted in unstable atmosphere thereby increasing the dispersion and dilution of pollutants resulting in low concentration of pollutants during this period. Compared to this, higher winter concentration was probably related to increased atmospheric stability during periods of fine weather and an increased frequency of temperature inversions and poor dispersion conditions. The trend in SPM concentration, which differed from that of other pollutants, showed an increase in monthly average during summer, this was mainly due to the frequent occurrence of sand storms. It was observed that there was remarkable decrease in the concentration of pollutants during monsoon period due to the scavenging action of rainwater resulting in the washing off of these pollutants.

Ozone is produced in atmosphere as a result of photooxidation of precursor gases such as CO, CH_4 and NMHCs in presence of sufficient amount of NOx. The concentration of ozone in Delhi was found higher during summer(figure 3c). The higher concentration of ozone during summer is probably due to favorable conditions like availability of sufficient solar radiation, which is the most important variable in photooxidation reaction.

Relation of pollutants to meteorological variables

Among the pollutants, CO shows high coefficient of variation(TABLE 3). Other variables, among gaseous and particulates, more are less, have same range of variation. Wind speed shows the highest variation among the meteorological inputs.

1. Dependence on temperature

An inverse relation was found between temperature and all pollutants except SPM. Significant, nega-

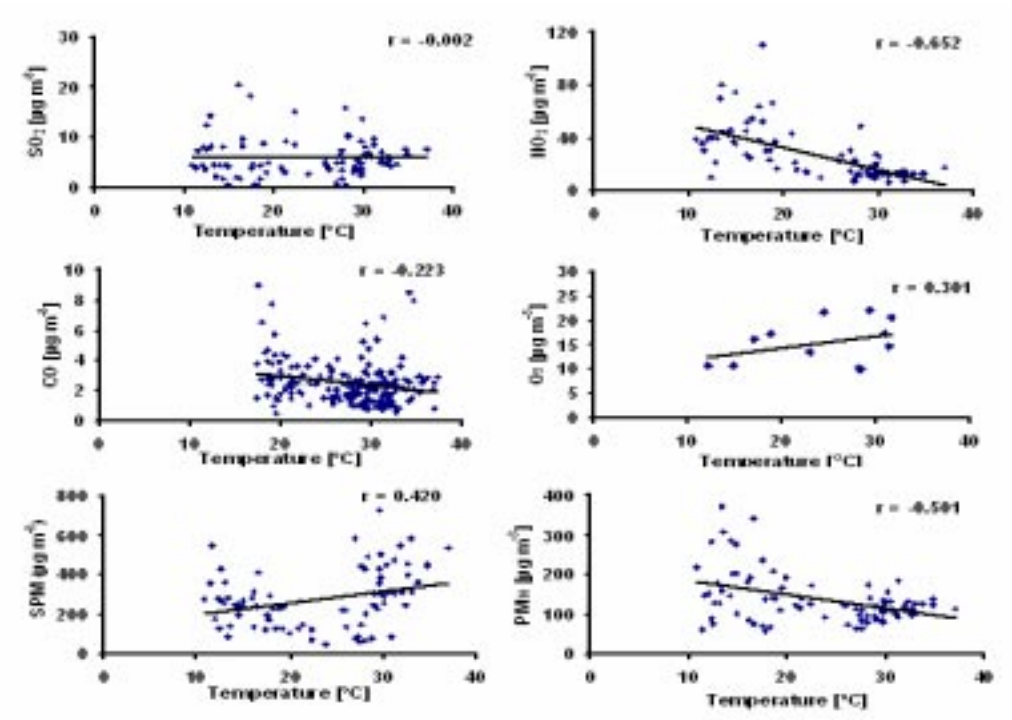

Figure 4: Graphs showing correlation between pollutants and temperature: (i)SO_2 (ii)NO_2 (iii)CO (iv)Ozone (v)SPM (vi)PM_{10}

TABLE 3: The mean, standard deviation and coefficient of variation of pollutants and meteorological parameters

	Mean	Standard deviation	Coefficient of variation(%)
Concentration			
SO_2	8.95	2.79	31.2
NO_2	37.7	11.98	31.7
CO	2.48	1.42	57.3
SPM	286.5	122.4	42.7
PM_{10}	133.1	53.26	40.0
O_3	14.9	3.9	26.2
Met. Variables			
Rel.humidity	67.4	16.07	23.8
Wind speed	0.55	0.29	52.7
Temperature	23.9	7.29	30.5

tive and high relationship was established between NO_2 and temperature but relation with SO_2 was weak and negative. This signifies that temperature changes significantly influence NO_2 concentration but have very less influence on SO_2 concentration(Figure 4). Also it has inverse impact on variation of CO and PM_{10}. O_3, which is a secondary pollutant, was positively related to temperature. This negative association of temperature with CO and NO_2 and positive relation with O_3 signify their reduction in concentration due to further conversion and participation in the formation of secondary pollutants. Among the particulates, SPM shows positive relation whereas PM_{10} is inversely related to temperature.

2. Influence of relative humidity

TABLE 4 shows that none of the pollutants are significantly correlated with humidity. Gaseous pollutant, especially NO_2, showed quite good association during winter months. SPM was inversely related to R.H during all period. The maximum concentration of SPM was observed when the moisture content of atmosphere was low. It can be said that the moisture content of air had important role in the sedimentation and removal process of particulates (mainly the bigger size) and thus helped in their minimization. Inverse and significant relation of R.H with O_3 is in good agreement with the scavenging action of the water droplets present in air. At high humidity, the water droplets act as barrier for the incoming solar radiation and thus, inhibiting the rate of photochemical reaction. Hence decrease in the concentration of O_3.

TABLE 4: Correlation coefficient(r) between pollutants and relative humidity

	A	M	J	J	A	S	O	N	D	J	F	M
SO_2	-0.199	0.001	0.251	-0.181	-0.216	0.390	0.185	-0.166	-0.128	-0.295	0.352	0.502
NO_2	0.244	0.127	0.107	-0.354	0.009	0.610	-0.347	-0.090	-0.101	0.169	0.663	-0.282
CO	-0.248	-0.180	-0.210	0.196	0.247	0.265	0.130	-0.211	-0.237	-0.205	-	-
SPM	-0.527	-0.604	-0.317	-0.035	-0.083	-0.298	-0.230	-0.201	-0.675	-0.624	-0.151	-0.565
PM_{10}	-0.334	0.015	-0.761	-0.017	-0.530	0.596	0.335	0.601	0.652	0.643	-0.393	-0.201
O_3	-0.747*	-0.125	-0400	-0.333	0.084	-	-0.212	-0.450*	0.375*	-0.449*	-0.277	-0.140**

** Correlation is significant at the 0.01 level(2-tailed), * Correlation is significant at the 0.05 level(2-tailed)

3. Influence of wind

Significant positive relationship of wind speed is established with SPM and it is found to be negatively correlated with PM_{10}(TABLE 5).

It can be observed(Figure 5) that the concentration of SPM was highest in the summer months (April-june) when wind speed was the highest. During summer, the dominant wind direction was from west and northwest part of India. Since, these regions of this country is mainly large arid and semi-arid regions, loss of moisture from top soil strata and combination of several anthropogenic factors like extensive urbanization, construction activities, increasing vehicular population, captive and domestic power generation contribute to high SPM concentration in ambient air. Also wind showed significant inverse relation with CO and NO_2. PM_{10} was not well correlated to wind speed. It appears that the major contribution of PM_{10} was from the emission from local vehicles during the combustion process.

The finding is further substantiated by the correlation coefficient values among primary pollutants (TABLE 6). The positive and significant correlation between PM_{10} and NO_2 signifies the probability of common source of emission that is from vehicles. The correlation of wind speed with O_3 was also found to be very less.

4. Influence of rainfall

To study the relation between pollutants and rainfall, the seasons have been categorized as monsoon(July-october) and non-monsoon period(rest of the months). A significant difference in the relation of pollutants with rainfall was observed according to this categorization (TABLE 7).

On the annual basis, all the pollutants were inversely related to rainfall but the relations were not very strong. During monsoon, very strong and inverse correlation was established. The major impact of rainfall was on the particulates signifying the clearing action of rainwater as they act as a coagulant and thus help in the settling process. Compared to this, during non-monsoon period, relation was not much strong with particulates. Not much significant differences in relation were observed between NO_2 and rainfall during monsoon and non-monsoon period.

TABLE 5: Correlation coefficient(r) values between pollutants and wind speed

Pollutants	Correlation coefficient (r)
SO_2	0.024
NO_2	-0.334**
CO	-0.164*
SPM	0.356**
PM_{10}	-0.181
O_3	0.195

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

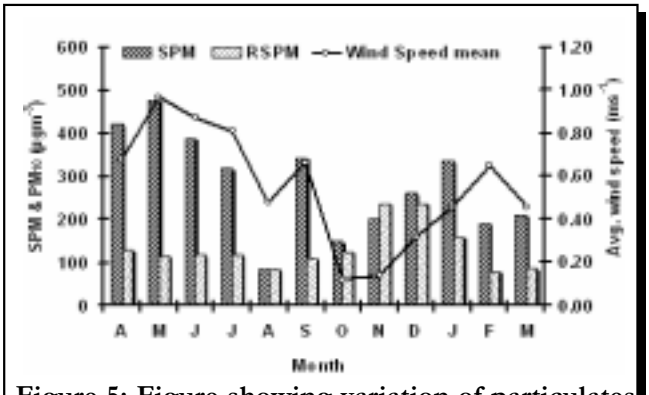

Figure 5: Figure showing variation of particulates with prevailing monthly mean wind speed.

Comparison of pre legislative and post legislative data

Our earlier studies were related to monitoring CO and NO_2 only. Hence, in order to estimate the impact of new regulations and changes in policies

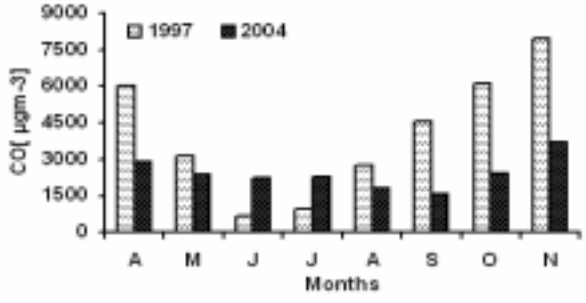

Figure 6: Comparison of monthly variation in CO concentrations in the year 1997 and 2004

TABLE 6: Correlation coefficient(r) between the primary pollutants

	SPM	PM_{10}	SO_2	CO
NO_2	-.136	.430**	-.135	.164
SPM	-	.050	.132	.005
PM_{10}	-	-	.011	.251
SO_2	-	-	-	.078

TABLE 7: Correlation coefficient(r) between rainfall and pollutants

	Monsoon	Non-monsoon	Annual
SO_2	-0.630	0.322	-0.130
NO_2	-0.313	-0.216	-0.138
CO	-0.341**	-0.144	-0.008
SPM	-0.986	0.561	-0.023
PM_{10}	-0.944	-0.133	-0.125
O_3	-0.013	-0.142	-0.123*

****Correlation is significant at the 0.01 level (2-tailed)**

*** Correlation is significant at the 0.05 level (2-tailed)**

on vehicular emissions, we have compared our observed data of CO and NO_2 in 1997 with the current data of 2004.

As can be observed from figure 6, there is a remarkable decrease in the CO concentration from 1997 to 2004. The average concentration of CO over the eight months period during pre-legislation was higher(4000µg m^{-3}) than present concentration (2400µg m^{-3}). But it is still above the permissible limit (2000µg m^{-3}, CPCB) most of the time. The concentrations of NO_2 and particulates remained more or less same after CNG conversion was implemented. Duggal and Pandey[18] reported the annual concentration of SPM was found to be in the range of 373-383µg m^{-3} during the year 1996-1998, whereas the present study shows the range to be 84-477µg m^{-3} (281µg m^{-3}, annual mean). There is a remarkable decrease in SPM concentration after the modification in fuel used though it is still above the prescribed norms(140µg m^{-3} annual average, CPCB).

The results, thus, indicate that CNG implementation in public transport system has helped to reduce the harmful emissions, especially fine particles and CO, but the problem of NO_2 is still causing concern. The consumption of diesel and petrol is reported[18] to be more or less the same as before and after the implementation of the legislation. This can be attributed to the increasing demand of personal vehicles, which account for more than 90% of the vehicles in Delhi. The level of particulates has also reduced to some extent but it is still a major problem. The contribution from natural sources for higher concentration of SPM cannot be ruled out.

CONCLUSION

The results showed clear variation in the seasonal pattern of pollutant concentration. Approximately 44% of the total concentration of CO, NO_2 and PM_{10} was during winter. For SO_2 and SPM, peak level was found during summer(42 and 48% respectively).

Among the meteorological factors, wind speed and temperature were found to be the most significant explanatory factors. Interestingly, among the particulates, there was wide variation in the seasonal distribution of SPM and PM_{10}. The study evidenced nonlinear relation among the particulates of different sizes confirming the dominating role of other factors and conditions prevailing in the area. The bigger size particles i.e. SPM were found to be positively and significantly associated with wind speed whereas no such relation was obtained in case of PM_{10}. The higher concentration of SPM during summer was probably due to prevailing wind direction from the W and SW region of country. Geographically the western part of India is comprised of arid and semi arid region, the moisture less soil in addition with other factors like contribution of anthropogenic activities is probable reason for high concentration during summer season. Based on the results, it can be concluded that the major source of SPM was due to contribution from distant sources

whereas the PM_{10} concentration was mainly due to locally generated sources(emissions from vehicles). An inverse and significant relation was observed between temperature and NO_2 while no significant relation was established with relative humidity. All the pollutants were found to be negatively correlated with rainfall.

Comparative study between the concentration of pollutant in the year 1997 and 2004 showed remarkable decrease in the concentration of CO while for NO_2 the situation is same even after implementation of several rules and policies.

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