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Impact of Change in Fuel Quality on PM10 in Delhi

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The problem of PM10 (particulate matter of diameter less than 10 micron) pollution has become serious due to its adverse effects on health of human beings (Dockery and Pope, 1994). The sources of particulate matter have been investigated in different regions in all over the world by several researchers (Eltayeb Mohamed et al. 1993; Vallius et al. 2003; Lee et al. 2002; Chow et al. 1992; Manoli et al. 2002; Sharma and Patil, 1994; Chow et al. 1996). In India, specifically in Delhi, the PM10 problem is significant and exceeds the guidelines stipulated by Central Pollution Control Board (CPCB). It is facing the problem of vehicular population growth especially during the past few decades, which results in the significant air pollution problem in the city. Existing industries, power plants and vehicular activities besides frequent dust storm mainly contribute the high concentration of the pollutants in Delhi. There are approximately 126,000 industrial (small and medium scale) units in Delhi out of which 98,000 units are categorized as non-conforming (Ministry of Environment & Forests, 1997). Vehicular pollution contributes 67% of the total air pollution load (approximately total of 3000 metric tones per day). The vehicular population observed in 2001 was around 3.6 million. It is estimated that on an average 370 to 600 vehicles are registered daily (Kathuria, 2002). The tremendous vehicular growth resulted in the high concentrations of particulate matter (TERI Report, 1997). To control PM10 levels in ambient air, the stringent standards for the vehicles and the fuels have been correspondingly improved. The policies adopted in Delhi to control vehicular emissions are; removal of lead from gasoline, control of sulphur content of diesel, change in automobile fuel, which led conversion of diesel fuel to Compressed Natural Gas (CNG) in the public transport and buses during 2001 (Central Pollution Control Board, 1999a). CNG is introduced, as it is a clean burning alternative fuel for vehicles. It has potential for reducing harmful emissions specifically particulates. It is estimated that diesel combustion emits 84 gms/km of particulates as compared to 11 gms/km in CNG (Nylund and Lawson, 2000).

In spite of all the emission control measures adopted for PM10, Delhi's air is still polluted. The objective of this study is therefore to examine the consequence of proposed fuel change on PM10 concentration in ambient air. For this purpose, time series analysis is performed to identify the trends and seasonal patterns in PM10 concentration.

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MATERIAL AND METHODS

Delhi, the capital city of India (Latitude 28°35'N, Longitude 77°15'E), is among the most polluted cities in the world. The city is located in central India and approximately 715ft above the mean sea level. Temperature generally varies from 46 °C in summer to 10 °C in winter. The area is under the influence of monsoon winds. The predominant wind direction generally ranges from NE-NW in winter and SE-SW in summer with average yearly rainfall of approximately 73cm. The region has a semi-arid climate that is often described as tropical plain, with extremely hot summers, heavy rainfalls in the monsoon months, and very cold winters. The summer months witness dust storms, while in winter months, mornings are foggy and evenings cause poor natural ventilation and high emission loads during peak traffic hours.

The PM10 data observed during 1999 to 2003 at two sites located at Town Hall and Sarojini Nagar in Delhi are selected to examine the impact of fuel change on ambient PM10 concentration. The two sites are named respectively as 'commercial' and 'residential' based on the relative activity. The data were obtained from the NEERI reports (NEERI, 2001; NEERI, 2002; NEERI, 2003; NEERI, 2004). The sampling method and analysis are described in the same reports and Katz (1977). The measurements were taken with 8 hourly frequency, monitored round the clock, and twice a week, thereby, 104 measurements per year. For the present study, the data with different time resolutions, such as 8 hourly frequency, 24 hourly frequency that is obtained by averaging the 8 hourly concentrations for a day, and monthly frequency are used.

To assess the effect of change in fuel quality on particulate matter levels in ambient air, the PM10 data during 1999 to 2003 are subjected to a trend analysis. The Seasonal Kendall (KS) test is used to analyze the statistical significance of trend, its direction and the slope, if the trend is monotonic (Hess et al. 2001). It is a well-known nonparametric test based on the Mann-Kendall test statistic. The Seasonal Kendall slope estimator provides the estimate of the magnitude of the trend and accounts for the seasonality present in the data. It is based on the signs of the difference between the successive observations. For example if the number of pluses is more than the minuses, the trend is upward otherwise it is downward. If the number of pluses is approximately equal to minuses, the trend is not significant. Mathematically, the Mann-Kendall test statistics (K_s) is given as;

$$K_s = \sum_{i<i'} sign(x_{i's} - x_{is}) \quad \text{---}(1)$$

Where x_{ik}'s are the samples for the kth season and ith year. The SK test statistic; $S = \sum_{s=1}^{p} K_s$ follows normal distribution with mean zero and variance V(K) under the null hypothesis of no significant trend. If S is positive, trend is upward whereas negative S indicates downward trend. Variance V(K) is given as;

$$V(K)=\frac{\left[n_s(n_s-1)(2n_s+5)-\sum_{t_s} t_s(t_s-1)(2t_s+5)\right]}{18} \quad ---(2)$$

Where n_s stands for number of samples in a season, t_s is the number of ties for the s^{th} season. The SK test statistics is then standardized and tested for its significance using Z statistics;

$$Z=\begin{cases} \frac{S-1}{\sqrt{V(S)}} & if\ S>0 \\ 0 & if\ S=0 \\ \frac{S+1}{\sqrt{V(S)}} & if\ S<0 \end{cases} \quad ---(3)$$

The null hypothesis of no significant trend is accepted at level α if absolute value of Z is less than $z_{1-\alpha/2}$. Apart from the test for significance of trend, Kendall test provide the estimate of slope of the trend, which is given as;

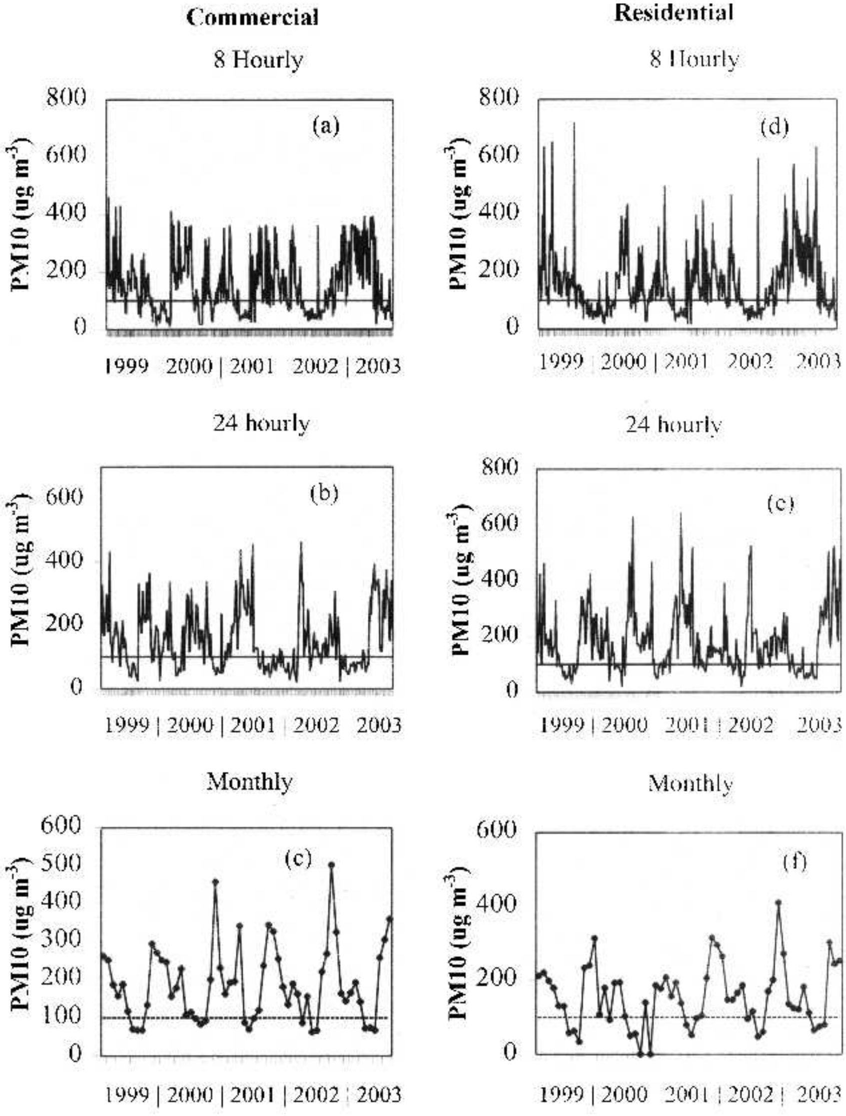
$$Q=\frac{x_{i'k}-x_{ik}}{i'-i}\ ;\ i'>i$$

The slope of the trend Q' can be estimated by taking the median of Q for all the pairs.

RESULTS AND DISCUSSION

Fig. 1 shows the PM10 time series at two sites observed during 1999 to 2003 in Delhi. It can be observed that daily PM10 concentration varies from 18 to 464 $\mu g\ m^{-3}$ with an average of 152 $\mu g\ m^{-3}$ at commercial site. At residential site, it ranges from 18 to 646 $\mu g\ m^{-3}$ with an average of 181 $\mu g\ m^{-3}$. 8 hourly PM10 concentration ranges from 10 to 463 $\mu g\ m^{-3}$ with an average of 162 $\mu g\ m^{-3}$ at commercial site whereas at residential site it varies from 15 to 719 $\mu g\ m^{-3}$ with an average of 156 $\mu g\ m^{-3}$. The monthly PM10 concentration ranges from 63 to 502 $\mu g\ m^{-3}$ at commercial and 34 to 410 $\mu g\ m^{-3}$ at residential site. A severe PM10 pollution problem at two sites can be observed from Fig. 1 as it exceeds the standard limits stipulated by CPCB (100 $\mu g\ m^{-3}$ for commercial and residential area for 24 hour frequency). An investigation of the variations of the PM10 concentration indicates the daily seasonal patterns in 8 hourly time series with maximum concentration in daytime and minimum concentration in morning hours. This is generally associated with transportation activity during daytime and domestic use of fossil fuels and biofuels (Monkkonen et al. 2004). Looking at the monthly variations, two peaks are generally observed in a year; larger one in December and smaller in April or May. Minimum concentration is observed in the wet months (June to September). Monkkonen et al. (2004) also evidenced these seasonal variations.

The Seasonal Kendall test is applied to the PM10 data with 8 hourly, daily and monthly frequencies separately. The estimated slope (Q'), Z statistics and its significance are given in Table 1. It can be observed that the p value is greater than



(-): PM10 concentraion; (- -): CPCB standards

Figure 1. PM10 concentration observed at two sites in Delhi
(a,b,c) - data observed at commercial site; (d,e,f) - data observed at residential site

0.1 for the data with different time resolutions. This indicates the insignificance of trend for PM10 time series observed at the two sites.

Describing the policy measures initiated to control and abate the pollution, two types of transport systems are predominant in Delhi; public and private. Buses form the backbone of the transport system in Delhi. These are the most economically and

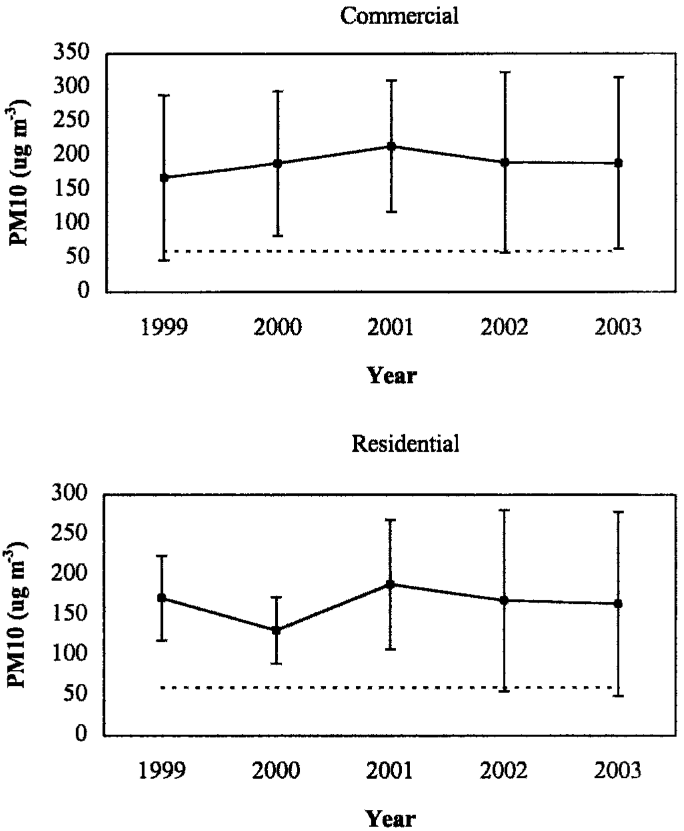
Table 1. Results of trend analysis.

Site	Time resolution	Slope (Q')	Z statistics	p value
Commercial	8 hourly	0.0029	0.1246	0.450
	24 hourly	-0.0526	-0.8731	0.191
	Monthly	0.0833	0.1403	0.444
Residential	8 hourly	0.0346	1.2034	0.114
	24 hourly	-0.0152	-0.2559	0.399
	Monthly	0.1165	0.1722	0.431

environmentally efficient means of providing transport services to most of the people. In Delhi, buses though constitute less than one percent of the vehicle fleet, but serve about half of all travel demand. The other mode of transport is based on gasoline-powered engines, which are either 2-stroke or 4-stroke. Two and three wheelers generally carry gasoline-powered engines. Pollution control depends heavily on the quality of the fuel. Due to this, several policies were implemented to change the quality of the fuel. This includes; complete removal of leaded petrol, phasing out of 17 years old commercial vehicles, desulphurization of diesel, replacement of all pre-1990 autos and taxis with new vehicles using clean fuel, conversion to CNG from diesel in public transport and introduction of maximum 1% benzene in petrol (Central Pollution Control Board, 1999a).

While analyzing the impact of above policies on PM10 concentration, it can be observed from Fig. 1 that the trend is not significant in PM10 time series with different time resolutions at the two sites. This is also supported by the results of KS test statistics. The insignificance of trend at the two sites indirectly suggests that the control measures adopted in the past have had no impact on reducing pollution at the two sites. Therefore the effect of CNG, which was argued to be the clean fuel for controlling the vehicular exhaust emissions of particulate matter, is not significant on PM10 pollution in Delhi. The findings however do not match with the study conducted by Goyal and Sidhartha (2003). However Gurjara et al. (2004) reported the insignificant impact of control measures on air quality by analyzing the association between emission trends and air quality.

Generally any implementation of policy measures to control the air pollution should lead to fall in the air pollution levels. The data analysis, however, does not indicate the same. As the advantages of the policies like CNG has been demonstrated elsewhere (Goyal and Sidhartha, 2003), it's insignificant effect on PM10 levels in Delhi is questionable. To investigate further, annual averages were plotted from 1999 to 2003 in Fig. 2. It can be observed that the PM10 levels increase from 1999 to 2001 and decrease in 2002 and approximately constant in 2003 at commercial site. At the residential site also, PM10 levels are approximately similar in 2002 and 2003, with fluctuations in the preceding years. A closer look indicates a decrease in PM10 concentration during 2002 compared to 2001 at the two sites but still continued to exceed the limits stipulated by CPCB. As the CNG was implemented during 2001, the effect of CNG is elaborated further by analyzing the trend observed during 1999 to 2001 only. The trend observed during 1999 to 2001 in annual PM10 concentration



(–): PM10 concentration; (- -): CPCB standards

Figure 2. Annual averages of PM10 concentration at two sites in Delhi

is increasing at commercial site where as at residential site, it is not monotonic. Considering the business as usual scenario, that is, if CNG would not have been introduced, the regression line was fitted to the three data points. R^2 values of 0.99 and 0.18 were obtained for the fitted line respectively for commercial and residential sites. Extrapolations for 2002 and 2003 were then obtained using the regression equation. It is observed that the levels are increasing. Estimated concentrations are 236 $\mu g\ m^{-3}$ in 2002 and 259 $\mu g\ m^{-3}$ in 2003 at commercial site and 180 $\mu g\ m^{-3}$ in 2002 and 189 $\mu g\ m^{-3}$ in 2003 at residential site. If the estimated concentration is higher than observed one, it indicates that some control measures might have been adopted that influenced the concentration levels to get reduced. The observed concentrations are 190 $\mu g\ m^{-3}$ in 2002 and 189 $\mu g\ m^{-3}$ in 2003 at commercial site and 168 $\mu g\ m^{-3}$ in 2002 and 164 $\mu g\ m^{-3}$ in 2003 at residential site. This indicates that the introduction of CNG has reduced the PM10 concentration at the two sites.

The insignificant trend in PM10 with short-term frequency may be due to the fact that, in urban areas, pollution comes mainly from vehicles consuming gasoline, especially 2 and 3 wheelers with 2-stroke engine. CNG has been implemented only for public transport and buses. Studies indicated that 2-stroke engine's exhaust contains almost 15–25% unburned fuel (Pundir, 2001). Hence even a modest 1% increase of oil may lead to 15% increase in particulate matter besides visible smoke (Central Pollution Control Board, 1999a). Two wheelers account for about two thirds of the total vehicular population in Delhi. The ban on 15-18 years old two wheelers was although suggested in the measures adopted to control the air pollution emissions (Central Pollution Control Board, 1999a), but not yet been fully implemented. Hence, controlling emissions from them could result in better control of PM10 pollution.

The factors such as climatic conditions, dust storms that prevail in Delhi, and meteorological variations also contribute to PM10 in ambient air. The insignificant trend in the data with short-term frequencies may be due to the contribution of these factors. In a study conducted by Goyal and Sidhartha (2002) on the effect of winds on particulate matter levels, high concentrations were associated with the winds coming from WSW to NW sector. It is also argued that most of the polluting industries are located in this direction and should be shifted down in another direction. CNG might be affecting the PM10 levels but the contribution of emissions from industries could be one of the reasons of insignificant trend. In a study on impact of policy instruments on air pollution levels, Kathuria (2002) observed an insignificant impact. It was reasoned that the conversion of public transport from diesel to CNG might have resulted in an immediate fall in emissions, but over time with an increased population of vehicles, the air quality might have returned to earlier level. Therefore, the contribution of other sources of PM10 in Delhi, which have not been taken into account to control the emission levels, may need to be assessed. For this, source apportionment studies need to be conducted in Delhi.

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