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Air Quality Status and Sources of PM10 in Kanpur City, India

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The sources of particulate matter has been investigated in different regions in all over the world by several researchers (Sharma and Patil 1992; Eltayeb Mohamed et al. 1993; Vallius et al. 2003; Lee et al. 2002; Kubilay and Saydam 1995; Schaug et al. 1990; Chow et al. 1992; Manoli et al. 2002; Li et al. 1993; Pinto et al. 1998; Sharma and Patil 1994; Chow et al. 1996). The increase in particulate matter levels causes serious atmospheric pollution problem, that in turn causes severe health effects. These particles enter into respiratory pulmonary system of human body and are responsible for asthma, painful breathing, chronic bronchitis, decreased lung functions, allergy. Particles containing fungi, viral or bacterial pathogens loading in ambient air may play a role in transmission of infectious diseases. The recent study has experienced that road transport to be a major source of PM 10 with other significant contribution from power plant, combustion process and non-combustion process in addition to road dust, refuse burning and marine aerosol (Chow et al. 1994). In India, no specific trend of PM10 in ten major cities is observed during the last decade (NEERI 1993-2001). However, the PM10 problem is still significant and exceeding the CPCB guidelines. The two-wheeler vehicles are increasingly plying on the roads during last decade. This indicates that there is no direct relationship between the vehicular exhaust and PM10 pollution. The detailed study is, therefore, required to identify the sources that are emitting PM10 in the air of urban cities in India.

As a case study, the source apportionment was, therefore, conducted for highly polluted city, Kanpur in India. Factor analysis was applied to apportion the sources of PM10. The PM10 was subjected to elemental composition, cations, anions, elemental carbon and benzene soluble organics (BSF). In addition to the factor analysis, trends during 1993 to 2001 were also analyzed to examine the status of PM10 in Kanpur city.

MATERIALS AND METHODS

Kanpur is a major industrial and trade center in the country. It is located in the Central region of UP State at latitude of 26° 06' N and longitude of 80° 26' E. The urban area of Kanpur is spread in 299 sq. km. The city has climate with extremely hot in summer (40 to 45°C) and cold winter (6 to 10°C) and annual average rainfall of 821 mm. The population is 22 lakhs as per the 1991 census. There are 3768 industries

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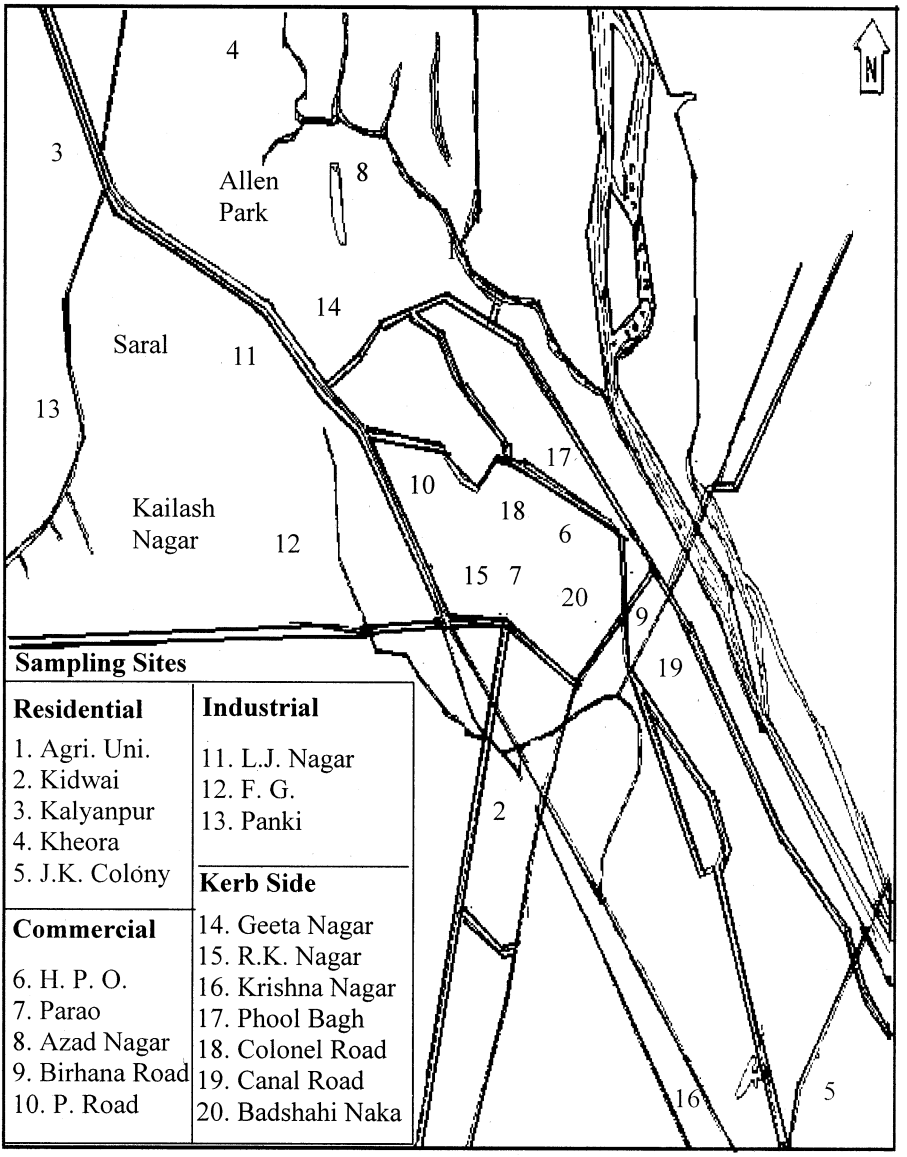

Figure 1. Location of ambient air monitoring sites in Kanpur city.

in Kanpur city including 75 large and medium scale units. These industries are confined to Panki, Jajmau, Dada Nagar and Armapur industrial areas. New small-scale industries are fast growing in Panki and Rania industrial areas towards south of the city. Leather industries are confined to Jajmau, where a cluster of 165 tanneries are existing. Most of the major industries in the city are closed since last 4-5 years. Only Thermal Power Plant, Fertilizer & Woolen mills are the major air pollution

sources. The motor vehicles registration rose by 1.5 times between 1988-1993 whereas the population increased 1.3 times during the same period.

The primary data collection was undertaken for a month during May 2002. Twenty representative sampling sites were selected throughout the city. Out of twenty sites, 5 sites were selected in Residential area, 5 sites in Commercial, 3 sites in Industrial and 7 sites as Kerb side (2 meters from the paved road) area. The locations of sampling sites have been shown in Fig. 1. PM10 were collected from the locations by operating Respirable Dust Sampler at an average flow rate of 1.5 m^3/min for 8 hourly basis round the clock on pre-weighed glass fibre filter paper and reweighed after sampling in order to determine the mass concentration of the particles collected. The concentrations of the particulate matter in ambient air were then computed on the net mass collected divided by the volume of the sampled. The PM10 samples were characterized for cations and anions as a prerequisite of the source apportionment study. For analysis of the toxic metals, the samples were prepared by digesting with nitric acid using Microwave Digestion System. The samples for metals such as Zn, Pb, Ni, Fe, Cr, Cd and Mn were analyzed by ICP-AES instrument. In case of anions (Cl^-, SO_4^{--}, NO_3^-), PM10 samples were extracted /Ultrasonicated in doubled distilled water and analyzed by Ion Chromatography method. The Elemental Carbon and Organic Carbon as benzene soluble organics were determined by Gravimetric method in duplicate samples. During the sample analysis, standard solutions were repeatedly aspirated to ensure calibrations of the instrument within the limit of the sample concentrations for precise and accurate results (Katz, 1977).

For trend analysis the data were obtained from NEERI reports (1993-2001). The data at three sites; industrial, commercial and residential was available. Separate analysis for each of the different activity zones like Industrial, Commercial, Residential and Kerb side (2 meters from the paved road) was conducted.

The detailed source apportionment analysis can best be carried out using receptor modeling. Out of the several techniques used, factor analysis, principle component method and chemical mass balance are most common. Each of these techniques has their own limitations and advantages. For chemical mass balance model, source profiles are required to relate them to the ambient concentration whereas for factor analysis, characterization of particulate matter collected at receptors is required. Factor analysis replaces a large set of Interco related variables with a smaller number of independent variables (Factors). The percent variability of each factor represents the total variance explained by that factor. To each species in a factor, factor loadings are associated that are nothing but the correlation of that species with the factor. Each factor indicates the presence of significant source. The identification of the sources associated with the factors is an important task and requires detailed study concerning knowledge of possible sources in an area, strength of the different sources and the type of emissions from the existing sources. The factor analysis assumes that the total concentration of each element is made up of the sum of elemental contributions from each of different pollution source components (Thurston and Spengler, 1985). The varimax rotated factor analysis technique based on the principal components has been used in the determination of the PM10 sources in Kanpur city. The components or factors rotated had eigen values greater than one after rotation.

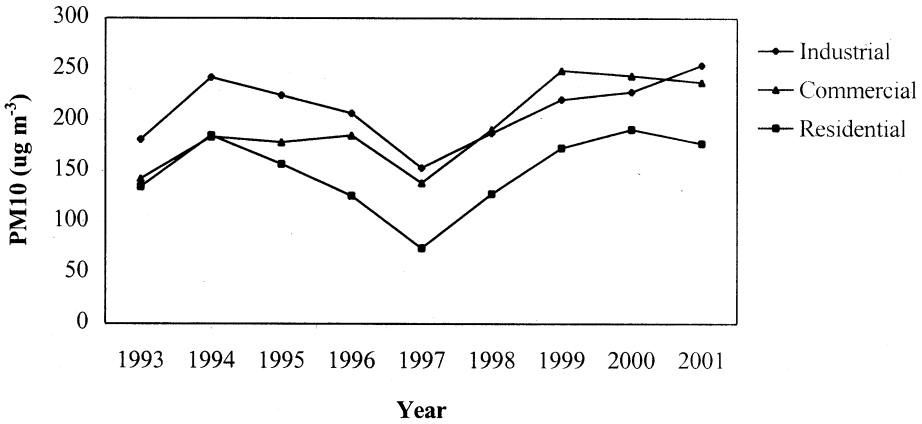

Figure 2. Variation in annual averaged PM10 concentration at three sites

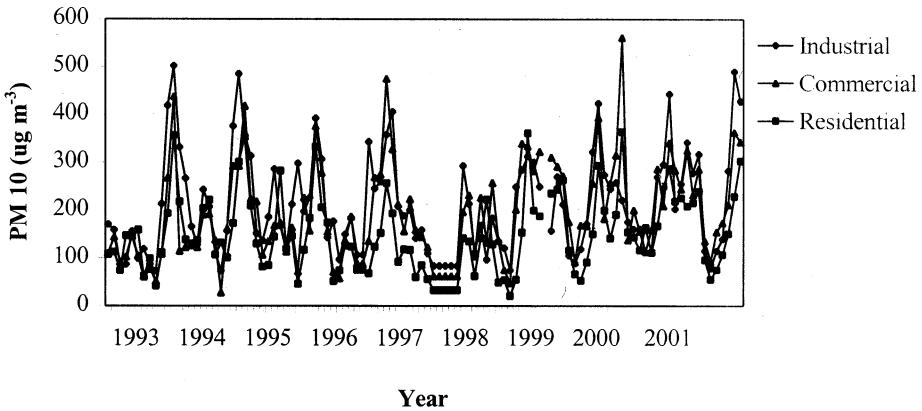

Figure 3. Time series of PM10 concentration observed at three sites in Kanpur during 1993 to 2001

RESULTS AND DISCUSSION

Before conducting the source apportionment study, the data available for Kanpur city from NEERI reports (1993-2001) was subjected to trend analysis to have a look on the status of PM10. It can be observed from Fig. 2 that the variations in the PM10 levels are almost same for three sites during 1993 to 2001. The hypothesis of no difference between the means and variances of the three time series was accepted at 5% level of significance. This indicates that the sources of PM10 at three sites are more or less the same. However the percentage contributions of the sources may vary due to the micrometeorology of the site. From Fig. 3, it can be observed that the trend is decreasing from 1993 to 1997 and slightly increasing from 1997 onwards. This may be due to the activities such as construction of buildings and vehicular growth from 1997 onwards that are causing increasing trend in PM10. There are several

activities, which contribute towards PM10 pollution in Kanpur city. It is, therefore, important to monitor the PM10 concentration in a wider spectrum of locations and to find its major sources. For this purpose, twenty monitoring sites were selected to cover the entire area of Kanpur city, representing residential, commercial, industrial and Kerb side. The monitoring was carried out for a month at each site for all criteria parameters. During the study period there were dust storms and thundershowers.

Table 1. Monthly averages of PM10 in different areas of Kanpur; Unit: $\mu g/m^3$.

Area	Min	Max	Mean	S.D.	98 Percentile
Residential	162	403	248	93.78	394
Commercial	51	205	116	63.90	199
Industrial	116	233	187	65	232
Kerb Side	80	280	139	76.98	269

While analyzing the air quality data based on monthly averages, it is observed that the monthly average of PM10 at all residential sites varies from 162 to 403 $\mu g/m^3$. For commercial sites it ranges from 51 to 205 $\mu g/m^3$ and at industrial sites and kerb side areas, PM10 ranges from 116 to 233 $\mu g/m^3$ and 80 to 281 $\mu g/m^3$ respectively. The PM10 concentration exceeded the limits at industrial, commercial and residential area. The area wise average of all the sites for PM10 is given in Table 1.

Table 2a. Factor analysis results for industrial and commercial area.

Species	Industrial Site				Commercial Site			
	F 1	F 2	F 3	F 4	F 1	F 2	F 3	F 4
PM10	-0.42	0.45	0.06	0.54	0.82	-0.02	0.23	-0.21
BSF	0.86	-0.12	0.42	0.11	0.04	0.93	0.05	0.08
Elemental Carbon	0.87	-0.14	0.41	0.10	0.02	0.93	0.04	0.08
Cl	-0.05	0.53	0.31	0.63	0.41	-0.46	0.55	0.34
NO_3^{--}	-0.16	-0.03	0.71	0.21	-0.37	0.01	0.01	0.89
SO_4^{--}	0.19	0.24	0.89	0.07	-0.18	0.25	-0.02	0.91
Na	0.10	-0.04	0.43	0.69	0.63	0.20	-0.04	0.07
K	0.38	0.52	0.48	0.04	0.55	-0.02	-0.08	-0.02
Zn	0.90	0.04	-0.20	0.10	0.19	0.86	0.03	0.14
Pb	-0.18	-0.16	-0.13	0.88	0.01	0.13	0.97	0.02
Cd	0.82	0.16	0.09	-0.41	-0.48	0.12	-0.28	-0.52
Ni	-0.10	0.85	0.044	0.09	-0.15	-0.47	0.78	-0.05
Mn	0.05	0.88	0.04	0.02	0.95	0.17	0.05	-0.12
Fe	0.02	0.84	0.08	0.22	0.87	-0.015	0.09	-0.33
Cr	0.56	0.29	0.29	-0.51	-0.16	0.54	-0.48	-0.03
Cu	-0.19	0.44	0.03	0.36	0.69	0.03	0.15	-0.16
% Variance	32.39	24.31	12.59	7.60	29.97	22.30	16.26	8.38
		Total % =		76.9		Total % =		76.9

F1, F2, F3 and F4 denotes for factor 1, factor 2, factor 3 and factor 4 respectively

For factor analysis with varimax rotation, the components with eigen value greater than one were retained, as the component with variance of one represents the amount

of variance explained by the original variable, so the component with variance greater than one represents more variance than by the original variable. Factor analysis was performed using STATISTICA (version 5) (1995). The factor loadings are depicted in Table 2a through 2b. The outcome of the factor analysis was considered along with activities around monitoring sites to infer about the sources of respirable particulates.

Table 2b. Factor analysis results for residential and kerb side area.

Species	Residential Site				Kerb Side			
	F 1	F 2	F 3	F 4	F 1	F 2	F 3	F 4
PM10	0.41	-0.05	0.79	-0.03	0.86	0.14	0.28	0.24
BSF	0.82	0.11	0.47	0.04	-0.07	0.95	-0.03	0.06
Elemental Carbon	0.81	0.11	0.45	0.05	-0.12	0.95	-0.04	0.06
Cl	0.29	0.11	0.74	-0.13	0.09	0.37	0.16	0.56
NO_3^{--}	0.94	0.16	0.09	0.04	-0.08	0.01	-0.05	-0.71
SO_4^{--}	0.78	-0.01	-0.22	0.14	0.36	-0.28	-0.05	0.79
Na	0.15	0.77	0.03	0.51	-0.07	0.06	0.84	0.26
K	0.01	0.83	0.20	-0.19	0.60	-0.21	0.49	0.41
Zn	0.09	-0.25	0.84	-0.02	0.11	0.34	-0.25	-0.25
Pb	0.04	0.34	-0.19	0.85	0.08	0.06	0.79	0.07
Cd	0.02	0.02	0.01	0.23	0.71	-0.02	-0.23	0.15
Ni	-0.16	0.86	0.19	0.26	0.17	0.04	0.94	-0.15
Mn	0.39	0.83	0.06	0.08	0.95	0.15	0.01	0.04
Fe	0.09	0.93	0.03	0.14	0.96	0.14	0.04	0.07
Cr	-0.04	0.14	0.04	-0.08	0.15	0.15	0.53	0.05
Cu	0.42	0.58	0.12	0.20	0.41	0.48	0.46	0.32
% Variance	39.21	20.21	11.91	6.31	31.13	16.19	14.14	9.80
	Total % =			77.64	Total % =			71.26

F1, F2, F3 and F4 denotes for factor 1, factor 2, factor 3 and factor 4 respectively

In industrial area, four factors together explained 77% of the variability (Table 2a), out of which factor 1 contributed 32%, factor 2 contributed 24%, factor 3 contributed 12% and factor 4 contributed 8%. Significant correlation of BSF, elemental carbon, Zn, Cd and Cr was observed with factor 1. Autoexhaust and DG sets are the main sources of BSF and elemental carbon in Kanpur. Zinc can be emitted from tyres and has been proposed a potential marker for traffic related emissions (Vallius et al. 2003). The presence of cadmium with elemental carbon and BSF indicates that the automobile tyres are a likely source of cadmium (Khandekar 1980). It can be observed that Factor 2 has high loading for K, Ni, Mn and Fe. Fe and Mn are crustal origin elements, which may be present in the resuspended dust. Airborne levels of Fe are generally related to construction work. Factor 3 has high correlation with nitrate and sulphate and this may be attributed to secondary aerosol formation, as the dominating source of sulphate and nitrate is secondary particles. Factor 4 has high loading for PM10, Cl, Na and Pb. This factor may be due to small-scale industrial emissions such as lead battery manufacturing and engineering industries.

At commercial area (Table 2a), four factors explaining 77% of the variance having eigen value greater than 1 were retained. The first component accounts for 30% of the

total variability. This factor represents resuspended dust as it has high factor loadings for PM10, Na, K, Mn, Fe and Cu. The second factor, which exhibits the 22% of the total variability, shows high correlation with BSF, elemental carbon and zinc. Autoexhaust and DG sets emissions can be attributed to this factor. Due to power failure, DG sets are commonly used in Kanpur. The third factor that accounts for 16% of the variability represents emissions from small scales industries like tyre molding, lead battery manufacturing and electroplating, as it is correlates with Cl, Pb and Ni. The fourth factor represents secondary aerosol source. This factor is correlated with nitrate and sulphate and explains 8% of the variability. Nitrate and sulphate are the predominant chemical components of secondary particles.

At residential area (Table 2b), factor analysis explained 77% of the variability out of which factor 1 accounts for 39%. This factor is highly correlated with BSF, elemental carbon, nitrate and sulphate. Autoexhaust and DG sets are dominating this factor. Factor 2 explained 20% of the variability and has high loading for Na, K, Ni, Mn and Fe. This factor can be attributed to resuspension of road dust. Factor 3 has high loading for PM10, Cl and Zn, and explains 12% of the variability and may be due to the contribution from domestic activities. Factor 4 explains 6% of the variability and correlates with sodium and lead. This factor may be due to earth crust elements.

At kerb side area (Table 2b), 71% of the variability was explained by factor analysis. Factor 1 explained 31% of the variability and has high loading for PM10, K, Cd, Mn and Fe. This factor represents road dust resuspension. Factor 2 accounts for 16% of the variability and indicates auto exhaust source as it has high loading for BSF and elemental carbon. Factor 3 explains 14% of the variability and has high correlation with Na, Pb, and Ni. This factor represents earth crust source. Factor 4 accounts for 10% of the variability and represents secondary aerosol formation source as it is correlated with Chloride and sulphate. The negative correlation with nitrate is, however, unexplained.

In brief, it can be observed that the trend in PM10 concentration in Kanpur city is increasing from 1997 due to the anthropogenic activities. Auto exhaust, DG sets and resuspension of the road dust are major sources of PM10 in Kanpur city. The results of factor analysis reveal that the sources of PM10 are more or less same in the four areas of the city. The study is based on limited data and gives just an indication of possible pollution sources and is not confirmative. To support the results of the factor analysis, emission inventory studies for point, area and line sources need to be conducted simultaneously with ambient air quality and kerb side monitoring.

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