PM₁₀ and heavy metals in sub-urban and rural atmospheric environments of Northern India

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Abstract

This study assesses the ambient air concentration of PM₁₀ and heavy metals at six different sites (including three sub-urban and three rural) in Roorkee, India. Monthly measurements were carried out continuously between January and March 2007 at all the sites. PM₁₀ concentrations at the rural sites ranged from 37-959 µg/m³ as compared to 151-422 µg/m³ at sub-urban sites. These concentrations were well above the CPCB (Central Pollution Control Board, Delhi) standards during all sampling months, except February. Conversely, lowest PM₁₀ concentration during February, were due to removal of particles by heavy rain (Karar et al., 2006) before the sampling days. In case of heavy metals, highest concentrations were 2.04, 30, 0.80, 7.13 and 15.6 ng/m³ for Cr, Fe, Mn, Zn and Al respectively at rural sites as compared to 0.28, 0.37 and 0.02 ng/m³ for Ni, Cu and Cd, respectively at an industrial site. Main sources of PM₁₀ and heavy metals at sub-urban sites were road dust, traffic exhaust, tire abrasion, industrial emissions and oil lubricants use at vehicle-servicing centre. Heavy metals and PM₁₀ at the rural sites came from coal and wood burning, sugar mill and brick furnace emissions, fertilizers use in farming, agricultural activity, road construction activity and the dust from long range transport along with naturally occurring re-suspended dust. Among all, wood burning was identified as the

most significant source of elevated PM₁₀ concentrations at rural sites. As opposed to the PM₁₀ that remains a concern, concentrations of all heavy metals were found to be far below the standard limits prescribed by WHO and EPA. It is therefore recommended that an integrated assessment of air pollution and health risk should be carried out in these rural and sub-urban areas.

Keywords: Air quality; Pollution; Particulate matter; Heavy metal; Roorkee; India.

1. Introduction

Anthropogenic emissions of air pollutants (like PM- Particulate Matter and heavy metals) that are linked with rapid urbanization and industrialization in developing countries is severely affecting the environment and human health (Lee et al., 2006). In India, air pollution has become a major concern at all levels. According to Goyal and Sidhartha. (2003), Ahmed et al. (2006) some of the key anthropogenic activities are industrial, agricultural, transportation, construction and burning of cooking fuels. Consequently, India is facing progressive deterioration in air quality due to growing levels of particulate matter, heavy metals and other air pollutants in ambient environment (Agrawal et al., 2002).

The ambient air PM consists of a core to which various chemicals like acids, metals, aromatic organic compounds, bacterial endotoxins and allergens, may get adsorbed. The amount of these chemicals increase with the reduction in size of particulate matter (Konarski et al., 2006). Exposure to these particles leads to increased health problems, high mortality rates and adverse changes in climatic conditions (Sun et al., 2004; Ahmed et al., 2006). Although the level of air pollutants (like heavy metals, PM and GHGs) are high in megacities and industrial areas but their effect is widespread rather than localized (Gurjar et al., 2008). Guttikunda et al. (2003) found that, though Asian megacities cover < 2% of the

land area, but they emit 16% of the total anthropogenic sulphur in Asia. Konarski et al. (2006) stated that concentrations of Cr and Pb were almost 20 times higher at the urban site- Legnica, in comparison to the rural environment. Rural areas adjacent to cities are also exposed increasingly to various air pollutants (Gomiscek et al., 2004), besides having their own pollution sources such as biomass burning, resuspended road dust and emissions from fertilized agriculture fields. A study by Parikh (2001) reported that biomass burning could contribute up to 10–100 times more concentrations of PM₁₀ than modern fuels in rural areas. This is mainly due to low thermal, combustion and heat transfer efficiencies of the biomass.

Along with the PM, an emerging issue is the role of ingested dust to metal toxicity in humans due to the tendency of metals to bio–accumulate (Lee et al., 2006, Figueroa et al., 2006; <http://www.lentech.com/feedback2.htm>). According to Cloquet et al. (2006), Lee and Chang (2000), Konarski et al. (2006), Gomiscek et al. (2004) and WHO (2003), the major sources of heavy metals and the PM are vehicular and industrial emissions in the urban and sub-urban areas, respectively. Konarski et al. (2006) recently performed a study in Poland, in which they compared the heavy metals between a town- Legnica and a rural site in sub-urbs of Krakow. None of the heavy metals were detected higher in the rural areas. A number of studies focusing on heavy metals and their sources report that Cu, Zn and Cd are mainly derived from car emissions, tire abrasion, combustion of fuels and lubricants, incineration and industrial emissions (Fergusson et al., 1991; Figueroa et al., 2006; Jaradat et al., 1998) – the sources, which are not generally found in rural areas.

So far, no study concerning air pollution at Northern part (especially Roorkee) of India has been carried out. The present study fills this data gap besides assessing the PM₁₀ and heavy

metal levels in selected study areas along with comparing them with the WHO and EPA air pollution standards. The data collected in this study can not only be utilized to validate air quality models in this rapidly developing area, but also be crucial to compare with data sets in other similar part of India or the world.

2. Methodology

2.1 Study Areas

Figure 1 shows the study areas and the sampling locations in Roorkee and Molna. Monthly measurements were carried out at all the three sub-urban sites in Roorkee and at the same number of rural sites in Molna (about 14 kms away from Roorkee) for January, February and March 2007, respectively. Roorkee ($29^{\circ} 51' N$ and $77^{\circ} 53' E$) is a sub-urban town in Uttarakhand of Northern India. As seen in Fig.1, sampling locations in Roorkee includes Ganeshpur (S_1), Civil lines (S_2) and Ramnagar (S_3), representing residential, commercial and industrial areas, respectively. It is 172 km north of the Indian capital New Delhi, located on bank of Ganga canal, and about 274 above mean sea level. Roorkee was once known for its clean environment, but rapid industrialization is changing its air quality from a clean to polluted place. According to Indian Census, 2001, Roorkee had a population of 252 784, which is now increasing rapidly due to migration, establishment of industries (e.g. glass, cement and footwear, etc.) and excellent educational institutes in and around this area. Molna includes three different sampling locations representing agricultural field (R_1), residential area (R_2) and school (R_3) (see Fig. 1).

2.2 Data collection

A sampling period covering morning and evening between 8 and 10 hours in each measurement day was selected (except for the commercial and industrial sites, where

sampling was done continuously for 8 to 10 hours). Respirable Dust Sampler (RDS-Envirotech, APM 460BL) was used to measure PM₁₀ (and heavy metals- Cr, Fe, Mn, Ni, Zn, Al, Cu, Cd) in the size range of 0.5 to 10 microns by passing air at a high flow-rate of 0.9 to 1.5 m³/ minute through high efficiency filter papers (Whatman's GF- 8'X 10'').

The amount of PM₁₀ collected was determined by measuring the change in weight of the filter paper (Ahmed et al., 2006; Nautiyal et al., 2007). For the determination of metal concentrations present in the atmosphere, one quarter of the exposed filter paper was cut into small pieces and digested completely with concentrated nitric acid (HNO₃). After successful completion of the digestion process a colorless solution was observed. The excess acid is boiled off and the dry material is re-dissolved in 2.5 ml of HNO₃ and 10 ml of double distilled water by gentle heating. The solution obtained is cooled and diluted to 100 ml in a graduated flask by triple washing with metal free water and filtered the total (Khillare et al., 2004; Gaghte and Hasan, 1999). Solution was then analyzed using ICP-MS for identification of metal concentrations.

3. Results and Discussion

3.1 Assessment of PM₁₀ and heavy metals at sub-urban sites in Roorkee

Table 1 summarizes monthly variations in the levels of heavy metals and PM₁₀ during the sampling period.

3.1.1 Variations in PM₁₀ levels

The observations revealed that, at the S₁ site, PM₁₀ concentrations were less in morning (262, 195, 151 µg/m³) as compared to evening (420, 199, 338 µg/m³) during January, February and March, respectively. This could be due to accumulation of pollutants as vehicular load increases with time and reaches to peak in the evening. Unfortunately, no

data was available for comparison between morning and evening concentrations of S₂ and S₃ sites, as continuous sampling was carried out for 8 to 10 hours. PM₁₀ values were less in the month of February in comparison to January and March for all the three sub-urban sites (Table 1). Heavy rainfall in February before sampling was considered the possible reason. Karar et al. (2006) found that PM₁₀ concentration were less during June in comparison to other months, probably due to washout of the particles, in similarity to our findings of February month (Table 1). Sun et al. (2004), found that in the winter aerosol samples the maximum average mass concentrations of PM₁₀ were 446.1, 573.2 and 631.9 µg/m³ at the traffic, industrial and residential sites in Beijing, respectively. These values were compared to the maximum PM₁₀ concentrations of our sites which were 341.3µg/m³ at S₁ (residential site), 329.6 µg/m³ at S₂ (compared to the traffic site) and 422.9 µg/m³ at S₃ (compared to industrial site) of sub-urban area– all these concentrations were less from the findings of Sun et al. (2004). As Roorkee is a very small town comparatively to highly developed megacity Beijing, hence the sources are more in Beijing in comparison to Roorkee.

3.1.2 Concentrations of heavy metals

At all sites, highest concentrations of all the heavy metals were measured in January at S₁ (Table 1). This may be attributed to the proximity of highway and existence of car and two wheeler-servicing centers located at both sides of the residential (S₁) sampling point (Table 1). In February and March (Table 1), heavy metals concentrations were found slightly higher at S₃ (though variations were observed during March) than at S₁ or S₂ sites. This could be because of various industrial activities, heavy flow of vehicles, badly maintained roads and constructional activities in the area. During the three months study period, highest concentrations of Cr and Zn were found at S₁ site during January, which was 1.33 and 6.59 ng/m³, respectively. This increase may be due to the emission of these

metals from tire abrasions and use of oil lubricants at the service centers. Presence of such sources and their association with increased Cr and Zn concentrations comply with the findings of Figueroa et al. (2006), Li et al. (2001) and Bhaskar et al. (2008). A similar study by Karar et al. (2006) found vehicle exhausts as a source of Cr that appears to be the case in our study as its concentrations were more at S₁ sub-urban site having heavy flow of traffic in comparison to the other two sites (Table 1). Another study on heavy metals by Jaradat et al. (1998) found ambient concentrations of Cu and Zn at roadsides of Jordan in the 0.26–0.60 and 0.12–0.38 $\mu\text{g}/\text{m}^3$, respectively. In our study concentrations found at S₂ sub-urban sites ranged from 0.0002–0.0004 $\mu\text{g}/\text{m}^3$ for Cu and 0.003–0.004 $\mu\text{g}/\text{m}^3$ for Zn; less from the findings of Jaradat et al. (1998).

Highest concentrations of Fe (20.81 ng/m^3), Mn (0.69 ng/m^3), Ni (0.29 ng/m^3), Al (13.89 ng/m^3), Cu (0.37 ng/m^3) and Cd (0.02 ng/m^3) were observed at S₃ site. This was expected because of presence of heavy metals in industrial emissions. The same was also observed by Sun et al. (2004), Cloquet et al. (2006) and Li et al. (2001) in their studies. Bhaskar et al. (2008) observed that concentrations of heavy metals in Madurai city ranged between 0.12 and 2.26 $\mu\text{g}/\text{m}^3$ for Fe, 0.08 and 16.51 $\mu\text{g}/\text{m}^3$ for Zn, and between 0.001 and 0.029 $\mu\text{g}/\text{m}^3$ for Cd, respectively. These values are relatively higher than those observed in our study (Table 1). The reason behind the concentrations might be the fact that Madurai, being popularly known as the city of temples, has high traffic density.

3.2 Assessment of PM₁₀ and heavy metals at rural sites in Molna

The selected sites of rural area vary in structural, social and atmospheric environment. Variations in the levels of heavy metals and PM₁₀ during January to March 2007 were determined and described as follows:

3.2.1 Variations in PM₁₀

The results revealed that during the entire study period highest PM₁₀ concentration (avg. 668.6 $\mu\text{g}/\text{m}^3$) was found at the R₂ site (Table 2). The possible reasons may be the burning of wood and dung cakes, which are traditional fuels for cooking in rural areas of India and burning of dry wood that is used for body heating purposes. These arguments are in line with the findings of Balakrishnan et al. (2002), they found that biomass combustion resulted in PM₁₀ concentrations ranging between 500 and 2,000 $\mu\text{g}/\text{m}^3$. The second highest PM₁₀ concentration was found at R₁ (453 $\mu\text{g}/\text{m}^3$). As seen in Table 2, highest PM₁₀ concentration at R₁ site during March may be attributed to the road construction near the site. PM₁₀ concentrations were the lowest in February as compared to January and March for all the sampling sites that may be due to the rainfall before every sampling campaign (Table 2). The increased PM₁₀ concentration at R₃ in March was about 304.3 $\mu\text{g}/\text{m}^3$; it was primarily due to combustion of diesel as fuel in tractors that are used for irrigating water in the crops as the site was very close to agricultural land. Furthermore, the use of biomass fuels (i.e. woods, dung cakes) increases during winters resulting in additional source of PM₁₀ in rural areas. All sites had higher PM₁₀ concentrations during evening hours in comparison to the morning sampling hours. For instance, during February, PM₁₀ concentrations during evening at the R₁ and R₂ sites were 63 and 163 $\mu\text{g}/\text{m}^3$, in comparison to morning concentrations of 37 and 115 $\mu\text{g}/\text{m}^3$ respectively. On the contrary, PM₁₀ concentrations at the R₃ site in February were less during evening (97 $\mu\text{g}/\text{m}^3$) in comparison to the morning hours (103 $\mu\text{g}/\text{m}^3$), as the agricultural work is more during morning hours.

3.2.2 Concentrations of heavy metals

As seen in Table 2, on comparison of heavy metals on a monthly basis among three sites (i.e. R₁, R₂ and R₃) in rural areas, it was found that average concentration was highest

1 at R₁ during January and March (except Cr). The reason might be combustion of fuel
2 during road construction activities, which were going on during that period (Sun et al.,
3 2004), mud-covered road in front of the school (Bhaskar et al., 2009; Yue et al., 2007).
4 Concentrations of some heavy metals including Cr, Ni and Zn during January, and Zn, Al,
5 Cd during February were the largest at R₃ site; this could be due to use of these heavy
6 metals in fertilizers, and coal and waste combustion
7 (<http://www.lenntech.com/periodic/elements/cu.htm>) at a distance of 2 Km from the field.
8 On the whole, largest concentrations of Cr (2.04 ng/m³), Fe (30 ng/m³), Mn (0.82 ng/m³),
9 Ni (0.19 ng/m³), Al (15.64 ng/m³), Cu (0.21 ng/m³) and Cd (0.01 ng/m³) were found at the
10 R₁ site during February and March. The sources are described in the above lines of same
11 section. Maximum concentration of Zn (7.13 ng/m³) was found at the R₃ site. The R₂ site
12 showed least concentrations of heavy metals. The source identified for increased
13 concentration of Al and other metals was the road construction going on nearby the R₁ site,
14 as identified by Sun et al. (2004). Presence of Cd at the rural sites (0.004 to 0.01ng/m³)
15 may be due to the wood and coal combustion, as was also reported by Gomiscek et al.
16 (2004) in their study where they found Cd in 0.07 to 0.87 ng/m³. Resuspension of road dust
17 and natural origin of these heavy metals could also be identified as some of the factors for
18 existence of the heavy metals at rural sites (Yue et al., 2007).
19 Morning and evening concentration of heavy metals were compared for rural sites. It was
20 observed that during February and March most of the heavy metals were higher during
21 evening in comparison to morning hours. During January variations were observed with
22 most of the metals showing significant decline during evening, the reason of which was not
23 clear.

3.3 Inter-comparison between rural and sub-urban sites

3.3.1 PM₁₀

The total average value for the concentration of PM₁₀ was higher at the sub-urban area (313.6 µg/m³) as compared to the rural sites (283.4µg/m³). Monthly averaged values indicate highest PM₁₀ concentrations during January at the R₂ site of rural area (668.6 µg/m³) followed by S₃ site (422.9 µg/m³) of sub-urban area. Reasons for this have been given earlier in Section 3.1.1. In February, maximum PM₁₀ concentrations were at the sub-urban site (Fig. 2) while varying concentrations were observed for all the sampling sites of rural and sub-urban area during March. Hence, we can conclude that PM₁₀ concentration is highly affected by use of biomass fuels as the existence of this source was the main difference between sub-urban and rural sites. Presence of sugar mill and a brick furnace situated at a distance of 3 and 7 kms away from the village towards the sub-urban site, contribute to both the selected locations.

3.3.2. Heavy Metals

However, WHO and EPA have no standards for average trimonthly concentrations, yet for inter-comparison of sub-urban and rural sites, heavy metals concentration were averaged over three months. Uppermost concentration of Cr (1.16 ng/m³), Fe (20.39 ng/m³) and Mn (0.60 ng/m³) was observed at school, while concentrations of Ni (0.16 ng/m³), Al (11.60 ng/m³), Cu (0.29 ng/m³) and Cd (0.15 ng/m³) were highest at the S₃ site. Highest average concentration of Zn (5.26 ng/m³) was at R₃, which might be due to its use in fertilizers. No significant impact of rain was observed on the concentrations of heavy metals during February sampling, which implies that heavy metals are not washed away with rain as PM₁₀ does. Similar results were observed by Karar et al. (2006).

During March, average concentrations of all heavy metals were highest at the school, except Cd and Cu, which were highest at the S₂ site (Fig. 3 a, b, c, d). Possible reasons

could be road construction, along with resuspension of road dust and long range transported dust.

3.4. Correlation coefficient of heavy metals

Correlation is a single number that describes the degree of relationship between two variables. By using this technique, we can identify the common sources for different pollutants by obtaining the correlation value. For identifying the relationship between various heavy metals, this matrix of correlation coefficient is generated for both sub-urban and rural sites (Tables 4 and 5).

In general, strong and positive correlations were observed between heavy metals for the sub-urban sites. For example, Fe had a strong correlation with all the heavy metals except Cr (Table 4). Possible reason for this could be their origin from combustion of fossil fuel in transport vehicles and re-suspension of road dust, as it was a major source at all the sub-urban sites. Negative correlations were observed only between Cr–Cu and Cu–Zn (Table 4). Based on this correlation value it seems that the source of Cu is different from that of Cr and Zn. The sources of Cu could either be landfills and waste disposal, industries or vehicles (<http://www.lenntech.com/periodic/elements/cu.htm>).

In case of rural sites, most of the heavy metals showed negative correlation. For example, Zn had a negative correlation with Fe, Mn, Al and Cu, with a slight positive relationship with Cr (0.05) and Ni (0.22). It was observed that Ni, Cr, Mn and Zn showed negative correlation with almost all the heavy metals except Cr and Ni. The sources of the above three metals can be identified as coal combustion, soil dust and vehicle exhaust, (Yue et al., 2007). Fe and Mn showed a strong correlation with Al, Cu and Cd, the possible source of these heavy metals might be combustion of fossil fuels (Yue et al., 2007, <http://www.lenntech.com/periodic/elements/cu.htm>).

4. Summary and conclusions

Measurements of PM₁₀ and heavy metals were carried out at three sub-urban sites and three rural sites between January and March 2007. The aim of the study was (i) to compare the concentration of PM₁₀ and heavy metals pollution in these areas, (ii) to identify the sources of PM₁₀ and heavy metals, and (iii) to assess the present standards of air quality as compared with WHO, EPA and CPCB guidelines. Following conclusions were drawn:

- This is conspicuous from the study that PM₁₀ concentrations are much higher than the proposed CPCB standards for ambient particulate levels of rural and urban areas. Only in February, concentrations of PM₁₀ at the rural sites were under the prescribed limits, due to rainfall before the sampling days. This shows the influence of meteorological conditions on the pollutants, as PM₁₀ is washed with rain leading to less concentration in the air.
- All the heavy metals concentrations of the sub-urban and rural sites were observed under the prescribed limits proposed by WHO and EPA; CPCB do not have standards for it.
- Main sources identified for the heavy metals and PM₁₀ at the rural sites were: coal and wood burning, emissions from sugar mill, resuspended dust, use of fertilizers in farming, agricultural activity, emissions from brick furnace, road construction activity and the dust from long range transport along with naturally occurring re-suspended dust. Among all, wood burning was identified as one of the most significant source of elevated PM₁₀ concentrations at the rural sites. However, this is the cheapest energy source in rural areas having low energy efficiency but its effect on atmospheric air pollution and deforestation are the highest. It is highly

recommended to discourage the wood burning activity in order to limit rising PM₁₀ concentrations and deforestation.

- Main sources of P_{M10} at sub-urban sites were road dust, traffic exhaust, tire abrasion, industrial emissions and use of oil lubricants at the vehicle-servicing centre.
- Since the sampling was carried out during the three winter months (i.e. January, February and March), low temperature and wind speed also favored the accumulation of pollutants, resulting in high concentrations during these months.
- Modest differences in concentrations of PM₁₀ and heavy metals between the sub-urban and rural sites could most probably be the result of transport of pollutants at the rural site from the nearby brick furnace, sugar mill and coal combustion in brick furnaces which were active nearby the rural area during sampling.

Though this study covers a short duration for measurements, but this is the first study of its kind representing sub-urban and rural areas of northern India. The results presented could be highly beneficial for future air quality measurements. Due to practical constraints, only a limited number of air pollutants are considered. Long term studies on an annual basis are required to identify the sources and concentrations of various air pollutants throughout the year. Added research in setting up pollution management and pollution control techniques is also warranted. These efforts will not only benefit the well being of humans, environment and our natural resources, it will also help the air quality management community and regulatory authorities to design effective mitigation measures.

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TABLES

Table 1- Monthly averaged ambient air concentrations ($\mu\text{g}/\text{m}^3$) at sub-urban sites in Roorkee.

Pollutants	Residential (S_1)			Commercial (S_2)		Industrial (S_3)		
	Jan	Feb	March	Jan	March	Jan	Feb	March
PM_{10}^a	341.3	197.6	244.15	329.6	319.9	422.9	249.6	406.4
Cr^b	1.33	0.29	0.45	0.28	0.15	0.19	0.24	0.14
Fe^b	19.4	10.33	14.91	11.56	15.41	10.30	20.81	14.24
Mn^b	0.58	0.33	0.46	0.40	0.48	0.38	0.69	0.47
Ni^b	0.25	0.09	0.09	0.12	0.11	0.10	0.29	0.12
Zn^b	6.59	3.83	3.45	4.27	3.01	3.06	4.82	3.34
Al^b	11.90	7.84	10.16	8.39	11.18	7.16	13.89	13.75
Cu^b	0.24	0.16	0.20	0.17	0.37	0.15	0.37	0.36
Cd^b	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01

Note: Superscripts “a” and “b” denote values in $\mu\text{g}/\text{m}^3$ and ng/m^3 , respectively.

Table 2 - Ambient air concentration at rural sites from Jan – March 2007

Pollutants	School (R ₁)			Residential (R ₂)			Agri. Field (R ₃)		
	Jan	Feb	March	Jan	Feb	March	Jan	Feb	March
PM ₁₀ ^a	283.3	50.2	453.9	668.6	139.2	374.6	176.3	100.3	304.3
Cr ^b	0.69	2.04	0.74	0.27	0.98	1.48	1.06	1.12	0.47
Fe ^b	12.84	18.33	30.00	9.29	12.34	21.59	12.09	10.14	15.26
Mn ^b	0.43	0.55	0.82	0.31	0.27	0.56	0.32	0.29	0.39
Ni ^b	0.11	0.19	0.15	0.08	0.12	0.13	0.13	0.15	0.11
Zn ^b	5.29	4.38	4.28	4.19	5.15	3.05	5.48	7.13	3.16
Al ^b	10.49	5.80	15.64	7.73	6.37	10.10	9.38	8.13	10.38
Cu ^b	0.17	0.21	0.21	0.11	0.14	0.15	0.12	0.15	0.18
Cd ^b	0.01	0.004	0.01	0.01	0.004	0.01	0.005	0.01	0.01

Note: Superscripts “a” and “b” denote values in µg/m³ and ng/m³, respectively.

Table 4. Correlation coefficient between heavy metals at sub-urban sites

<i>Heavy metals</i>	<i>Cr</i>	<i>Fe</i>	<i>Mn</i>	<i>Ni</i>	<i>Zn</i>	<i>Al</i>	<i>Cu</i>	<i>Cd</i>
Cr	1							
Fe	0.48	1						
Mn	0.34	0.98	1					
Ni	0.50	0.89	0.90	1				
Zn	0.87	0.65	0.56	0.80	1			
Al	0.17	0.86	0.88	0.67	0.35	1		
Cu	-0.16	0.64	0.69	0.41	-0.003	0.88	1	
Cd	0.05	0.90	0.94	0.80	0.34	0.85	0.78	1

Table 5. Correlation coefficient between heavy metals at rural sites

<i>Heavy metals</i>	<i>Cr</i>	<i>Fe</i>	<i>Mn</i>	<i>Ni</i>	<i>Zn</i>	<i>Al</i>	<i>Cu</i>	<i>Cd</i>
Cr	1							
Fe	0.24	1						
Mn	0.23	0.97	1					
Ni	0.84	0.41	0.41	1				
Zn	0.05	-0.48	-0.44	0.22	1			
Al	-0.38	0.70	0.70	-0.13	-0.24	1		
Cu	0.37	0.68	0.73	0.66	-0.21	0.34	1	
Cd	-0.21	0.75	0.78	-0.11	-0.39	0.84	0.22	1

APPENDIX

Table 3. Standard criteria for PM₁₀ and heavy metals in air used by WHO and EPA (Frederic, 2002)

<i>S. No.</i>	<i>Pollutants</i>	<i>Standard Concentration</i>
1.	PM ₁₀ ^a (Industrial)	150 µg/m ³
2.	PM ₁₀ ^a (Residential, Rural and other areas)	100 µg/m ³
3.	PM ₁₀ ^a Sensitive	75 µg/m ³
4.	Cr	0.1 mg/ m ³
5.	Fe	6 mg/m ³
6.	Mn	0.05µg/m ³ Rural; 0.3µg/m ³ Urban
7.	Ni	0.002µg/m ³ Rural; 0.015µg/m ³ Urban
8.	Cu	0.01µg/m ³ Rural; 0.257µg/m ³ Urban
9.	Cd	1-5ng/m ³ Rural; 10-20ng/m ³ Urban
10.	Zn and Al	Not issued by health authorities

^a 24 hourly values should met 98% of the time in a year. However, it may exceed 2% of the time but not on two consecutive days (Source:

www.cpcb.nic.in/National_Ambient_Air_Quality_Standards.php)

FIGURES

Fig. 1. Air quality monitoring and sampling locations (shown in red outline)

Fig.2. Monthly variations in PM_{10} concentrations at rural and sub-urban sites

Fig. 3a) Concentrations of Cr and Fe at rural and sub-urban sites during January

Fig. 3b) Concentrations of Mn and Ni at rural and sub-urban sites from January-March

Fig. 3c) Concentrations of Zn and Al at rural and sub-urban sites from January-March

Fig. 3d) Concentrations of Cu and Cd at rural and sub-urban sites from January-March

FIGURES CAPTIONS

Fig. 1. Air quality monitoring and sampling locations (shown in red outline)

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Fig. 3d) Concentrations of Cu and Cd at rural and sub-urban sites from January-March